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TITLE

FINAL REPORT

ARMS CONTROL IMPLICATIONS OF STRATEGIC OFFENSIVE WEAPON SYSTEMS (U)

VOLUME IV

Technological Feasibility of Launch-On-Warning and Flyout Under Attack (U)

ACDA/ST-196

PREPARED FOR

The U.S. Arms Control and Disarmament Agency

PREPARED BY

AEROSPACE SYSTEMS ANALYSIS

MCDONNELL DOUGLAS ASTRONAUTICS COMPANY

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PREFACE

This document is Volume IV of a seven-volume final report which, together with two data books, presents the results of Contract ACDA/ST-196, a study of the Arms Control Implications of Strategic Offensive Weapon Systems. The data and analyses reported in these volumes and data books used the results reported previously for Contracts ACDA/ST-147 and ACDA/ST-180, and represent a significant extension in scope and depth of those results. The primary emphasis in Contract ACDA/ST-196 was on analysis of survivability and penetration issues arising from the interaction of strategic arms limitations and the advancing technology of strategic weaponry. In addition, analysis of Nth country offensive missile development capability was performed.

To provide a consistent, accessible, and timely data base for the analyses performed, the data books on U. S. and Soviet strategic offensive weapon systems, which were prepared under Contracts ACDA/ST-147 and ACDA/ST-180, were updated and extended.

This study provided the U. S. Arms Control and Disarmament Agency (ACDA) with the following products:

A. An updating of the data base for U. S. and Soviet offensive weapon systems:

   1. U. S. Strategic Offensive Weapon Systems Data Book (U), McDonnell Douglas Corporation, Report No. MDC G2289, April 1971.

   2. USSR Strategic Offensive Weapon Systems Data Book (U), McDonnell Douglas Corporation, Report No. MDC G2288, April 1971.

B. A final report comprised of seven volumes:

   1. Volume I: Summary (U).

   2. Volume II: Strategic Missile Characteristics and Related Arms Control Constraints (U).

3. Volume III: NCA Defense Related Issues (U).

4. Volume IV: Technological Feasibility of Launch-On-Warning and Flyout Under Attack (U).

5. Volume V: SSBN Survivability (U).

6. Volume VI: Forward-Based Aircraft In A Strategic Role (U).

7. Volume VII: Impact of Technology Exchange On Nth Country Development of Ballistic Missile Delivery Systems (U).

This study was performed under the cognizance and direction of the ACDA Science and Technology Bureau, and the advice and cooperation of the Project Officer, E. E. Anschutz, is gratefully acknowledged. Other ACDA personnel whose assistance was invaluable to the study are J. B. Resnick (Volume III) and C. Henkin (Volume VII).

This final report was prepared by the members of the Arms Control Studies Group at the McDonnell Douglas Astronautics Company (MDAC). This group consists of:

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Additionally, many of the engineers and scientists in the Development Engineering and Advanced Systems and Technology organizations at MDAC contributed to the study.

This volume addresses the technological issues bearing on the feasibility of alternatives to riding out a counterforce attack on the Minuteman. Two possibilities are investigated--launching before a pindown attack can be initiated and flying out through a pindown attack. The effects of a nuclear environment on Minuteman during boost are discussed, along with possible approaches to hardening the system.

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Section 1

INTRODUCTION

Even though an agreement may emerge from SALT within the next year, the survivability of the land-based ICBM force remains one of the crucial strategic issues. Even if the agreement includes a moratorium on offensive deployment, it is within the limits of technological feasibility for the Soviets to improve the accuracy of their ICBM's to the point that they are a definite threat to Minuteman survivability.

Nothing short of rigorous, enforceable control of qualitative improvements in offensive systems can prevent Soviet achievement of counterforce capability if they choose to exercise this option. Such control is highly unlikely. On the other hand, it is quite possible that the ABM agreement will preclude defense of the Minuteman and it is almost certain that if a defense is allowed it will only be a token; therefore, other options must be sought to preserve the land-based force.

One way to improve Minuteman survivability would be for the U. S. to adopt some variation of launch-on-warning (LOW). LOW, if adopted by the U. S., would make the survivability of Minuteman insensitive to qualitative improvements in the Soviet strategic missile force. With the deployment of satellite-based warning systems, the U. S. has nearly 30 minutes warning of counterforce attack on the Minuteman by Soviet ICBM's. If the Minuteman can be launched within that 30-minute interval, the accuracy of the Soviet ICBM's will be unimportant because the Minuteman silos will be empty.

While LOW certainly represents a solution to the Minuteman survivability problem, it is not without drawbacks. First, there is the possible problem that the command and control machinery which is required to launch Minuteman may be incapable of reacting within 30 minutes--particularly, if the attack is a complete surprise. If LOW is feasible, two other major objections raised against a LOW doctrine are: (1) LOW increases the risk of nuclear war because the National Command Authority (NCA) must initiate its response on the basis of information from potentially fallible sensors; and (2) there may be strategies available to the attacker whereby he could deny a LOW capability even if the U. S. were willing to implement such a doctrine. Pindown using the Soviet SLBM's is the most likely strategy for this purpose.

This study examined the technological issues associated with the three objections cited above. The feasibility of launching before the ICBM's could arrive was examined. Options open to a potential attacker to defeat LOW were also examined; these options ranged from attempting to mask his intent in order to delay U.S. response, to use of depressed trajectory SLBM's in an all-out pindown attack to keep the Minuteman bottled up until the ICBM's can arrive. A simple flyout strategy was developed which provides guaranteed survival for some portion of the Minuteman force against all but very large inventory pindown attacks. Throughout the study an attempt was made to maintain the viewpoint of a Soviet planner. Because deterrence is so much a product of perceived rather than actual capability, the credibility of LOW or flyout capability to an outside observer is perhaps more important than their actual feasibility.

This report is organized as follows. Section 2 contains a summary of the report and its conclusions. Section 3 examines preemptive scenarios, isolating those elements which bear on LOW feasibility. Sections 4 and 5 examine the feasibility of LOW (launch before pindown is possible) and flyout under attack. Section 6 discusses U.S. options of both systems' development and arms control proposals which could eliminate the threat of a pindown attack. Two appendixes contain a discussion of Minuteman vulnerability to nuclear effects and ways to increase the hardness of the system: Appendix A discusses the propulsion system, motor case and structures while Appendix B discusses the guidance subsystem.

Section 2
SUMMARY

One of the principal objections to LOW as a strategy can be dismissed after an examination of reasonable preemptive scenarios. There is no attack strategy which could be guaranteed to result in effective pindown and which conceivably could be construed as anything but a deliberate counterforce attack. The inventory required for effective pindown is too large and the coordination of too many platforms (SLBM and ICBM) is necessary for a pindown attack to be regarded as either accidental or unauthorized.

The danger of a false alarm triggering a nuclear war is also exaggerated. The probability of a false alarm by any one of the warning systems is negligible; the probability that two warning systems measuring entirely different phenomena would report correlated false alarms at the same time is infinitesimal. More important, the nature of a serious pre-emptive attack is such that time-sensitive targets (such as SAC bases, command and control centers, etc.) must be attacked in the first few minutes if the attack is to succeed. Thus, the evidence of the warning systems would be corroborated by nuclear bursts on or over the United States before the Minuteman could be released.

The remaining arguments against LOW are dealt with in more detail in the following subsections.

2.1 LAUNCH-ON-WARNING

The major problem associated with implementing a LOW doctrine--other than the willingness of the NCA to actually employ such a policy--is the possibility that the attacker may be able to pin the Minuteman down before the launch command can actually be executed and the missiles get away safely. For the purpose of this study, LOW was assumed to be denied if the enemy can detonate an SLBM warhead over the Minuteman wing before the first Minuteman which can be launched is outside the lethal radius of the warhead.

There are physical limitations to the strategic warning and command systems, as well as built-in safeguards to minimize the chance of an accidental launch; together, these factors result in a protracted interval between the first perception of an attack and the flyout to safety of the

first missile launched. The most important and least predictable delay is associated with the assembly of the NCA and the time it requires to assimilate the situation, understand the options, and determine a response. This delay is obviously highly scenario dependent; if the nation is in a state of strategic alert, the NCA will be secure and much of the decision process will be speeded up. On the other hand, if the attack is a surprise, just assembling the NCA and determining who is in charge could consume hours. Other significant delays in the command link are the four minutes required for formatting and transmitting the launch command from the National Military Command Center (NMCC) to the Launch Control Center (LCC), and the 11 minutes needed for decoding and verifying the message and initiating the launch.* In addition, the missile is extremely vulnerable to nuclear effects throughout powered flight (another 175 seconds for Minuteman), although after approximately 150 seconds of flight the missile is far enough downrange that bursts in the vicinity of the launch area are not likely to affect it.

Table 2-1 shows how the Minuteman response time compares with Soviet SLBM time of flight to the various Minuteman wings. Four different cases which could arise over the next few years are considered. This table assumes that no time is consumed by the NCA decision-making process.

Current U.S. and Soviet capabilities are shown in the first row of Table 2-1. This case assumes that the U.S. does not yet have a satellite-based, early-warning system over the SLBM launch areas and restricts the Soviet Union to nominal trajectories. Even so, the Minuteman clearly cannot escape before the first Soviet missiles arrive.

The other three lines of Table 2-1 represent hypothetical situations which could be possible in the time periods indicated. By 1973, the U.S. will have a boost-phase warning capability in the SLBM launch regions. This will effect considerable saving in time to launch Minuteman but the saving is not adequate to insure Minuteman launch before the SLBM could arrive. In addition, the improvement could be offset by Soviet development of a depressed-trajectory threat. It might also be possible by 1973, or thereafter, for the U.S. to improve Minuteman launch-crew capability to meet the original standard of six minutes from receipt of command to execution. If this could be done or if an equivalent length of time could be saved in some other way, and the Soviets do not develop a depressed trajectory threat, a launch-on-warning capability would be marginal, given the highly optimistic assumption that the NCA is ready to react instantaneously. Once again, however, a depressed-trajectory threat would be adequate to forestall such a capability.

*This interval is determined by the slowest crew for fail-safe and attack coordination reasons and by no means is a lower bound on the time required.

Table 2-1

FEASIBILITY OF EVADING PINDOWN (U)
(Attack Starts at T = 0; All Units in Seconds)
Strategic Alert

Time Period	SLBM Time of Flight: Wings II, III, V, & VI	SLBM Time of Flight: Wings I & IV	Earliest Possible Minuteman Launch Time	Earliest Time to Safety
Current	730 - 850	600	1,100	1,275
1973 - 1976	580* - 740*	450*	985**	1,160
1973 - 1976	580* - 740*	450*	685***	860
1975 - 1980	910* - 1,020****	700*	685***	860

*Depressed trajectory threat.

**Boost phase warning system.

***Improved launch crew facility.

****500-nmi submarine standoff; new SLBM required for range.

The only way it appears possible to guarantee that Minuteman could fly out to safety would be for the U.S. to enforce, either through agreement or by ASW capability, a Soviet submarine standoff from our shores of at least 500 miles. This would put the north-central Minuteman wings out of range of the SS-N-6. Even if the Soviets deploy the SS-NX-8 or some other longer-range SLBM, with depressed trajectory capability at this range, LOW would still be possible although NCA reaction time would have to be very fast (under two minutes).

The discussion above does not rule out the possibility that LOW may appear credible to the Soviets. A Soviet planner is unlikely to have detailed insight into U.S. command and control delays. His assessment of U.S. response time is likely to be predicated principally on his experience with his own system; it may be either smaller or greater than the actual delay in the U.S. system. Consequently, the discussions above do not necessarily indicate that a Soviet planner would be willing to discount a LOW threat, especially in a strategic alert situation.

2.2 FEASIBILITY OF PINDOWN

If the Soviet Union were to attempt a preemptive attack against U.S. strategic forces within the next decade, the mission of actually destroying the hardened Minuteman silos necessarily would fall to the SS-9's and SS-11's. To attain the accuracy required, these ICBM systems would have to fly close to nominal ballistic trajectories and, thus, would require at least 30 minutes to reach the Minuteman silos from their locations in the central Soviet Union. On the other hand, Soviet SLBM's on depressed trajectories can reach the Minuteman silos in 10 to 12 minutes. Minuteman can be ready to launch 19 minutes (given current warning and command delays) after the attack begins; with suitable adjustments in doctrine and systems, and with boost-phase warning, this interval potentially could be reduced to 11 minutes or less. If the Soviets do not pin the Minuteman in their silos, the entire force could be launched before the preemptive strike occurred.

If the Soviets elect to pin the Minuteman down, it is by no means certain they can succeed unless they have a large inventory of SLBM's to assign to the job. The lethal mechanisms which are most effective in the pindown attack (viz, x-rays) do not persist; they are released and dissipated within microseconds after the bomb bursts. Thus, to insure pindown, the attacker must detonate bursts at frequent intervals in order that any Minuteman attempting to flyout is within a lethal radius of at least one burst at some time during powered flight. Pindown must start before the first Minuteman could be launched and continue until the first wave of ICBM's arrives.

Factors (in addition to the duration of the attack) which determine the number of weapons required to insure pindown are (1) geometry of the Minuteman wing, (2) hardness of the Minuteman during powered flight, and (3) yield of the attacking weapon.

Wing geometry has a significant effect on pindown requirements. The optimum pindown strategy is to detonate warheads at approximately 25 nmi altitude about 25 nmi north of the Minuteman wing. The number of bursts required is determined by RV lethal radius and the width of the threat tube. The latter, in turn, is a function of wing geometry and the angle subtended by potential targets in the Soviet Union (in this study only targets in the western half of the Soviet Union were considered). The interval between successive bursts is determined by the time required for a Minuteman to fly through the lethal volume generated by a single burst. A wing which is wide from east to west, such as Wing I, requires more bursts to cover the threat tube than one which is narrow, such as Wing VI. However, Wing VI is long in the north-south direction and, therefore, the bursts must be repeated more frequently because a missile launched from the southern-most part of the wing can traverse the lethal volume generated by the burst in 40 seconds. Wings II through V have approximately the same overall geometric configuration and require identical pindown attacks(two bursts every 50 seconds). Table 2-2 summarizes the guaranteed-pindown requirements for all the wings if Minuteman hardness is 1 cal/cm^2 and the SLBM warhead yield is 2 Mt.

The pindown requirement is extremely sensitive to the attacker's assessment of Minuteman hardness. The number of RV's required varies with the square of the hardness level because a variation in hardness changes both the number required to cover the width of the threat tube and also the time required for Minuteman to fly through the lethal volume. The sensitivity increases at higher hardness levels (4 to 5 cal/cm^2) because the depth of the threat tube becomes large relative to the lethal radius of the warhead, thus necessitating tandem bursts (one above the other) to insure that no Minuteman can escape.

The overall impact impact of hardness is shown in Figure 2-1 in terms of the number of RV's required per minute of pindown for both 1- and 2-Mt SLBM warheads. It is, of course, impossible to state what the Soviet assessment of Minuteman vulnerability might be, but is is reasonable to guess that he would prefer to work with sure-kill values rather than sure-safe values. For Minuteman, the sure-kill levels are 2 to 10 times the sure-safe numbers.

2.3 FLYOUT AGAINST A DEFICIENT PINDOWN ATTACK

The Soviet planner's total inventory requirements for a guaranteed pindown attack can be estimated from Figure 2-1. If the planner is fairly

Table 2-2

SOVIET MINIMUM GUARANTEED PINDOWN REQUIREMENT (U)

Wing	Number of Bursts	Interval Between Bursts	Maximum Pindown Duration	Number of RV's Required
I	3	50	20	72
II	2	50	20	48
III	2	50	20	48
IV	2	50	22	52
V	2	50	20	48
VI	2	40	20	60

SLBM Yield = 2 Mt.

Minuteman Vulnerability 1 cal/cm^2.

reckless and assesses Minuteman hardness at 1 cal/cm^2, and if his SLBM warheads have their estimated yield of 1 Mt, 20 minutes of pindown will require 600 SLBM's on-station within 100 to 200 miles of the U. S. coast. Because it is practical to maintain no more than about two-thirds of an SLBM force on patrol at any one time,* the Soviet planner's requirement for a successful pindown attack under these circumstances is 900 missiles and 56 submarines. At his current SSBN production rate, he could not mount a guaranteed pindown attack against the Minuteman for at least five years.

Although the Soviet SLBM force is inadequate to enforce pindown, it may be argued that they might try such an attack nonetheless, relying on U. S. uncertainty as to the nature and magnitude of the attack to keep the Minutemen bottled up. If they were to attempt such a strategy, the U. S. has the option of flying out in such a way that the survival of at least some Minutemen is guaranteed. This can be done very simply. Minuteman launches are timed and sequenced in such a way that no pindown RV

*Actual Soviet ballistic missile submarine operations have not approached this figure. Normally, less than one-fourth of the Soviet SLBM fleet is at sea and these do not usually patrol within 200 nmi of the U. S. coast.

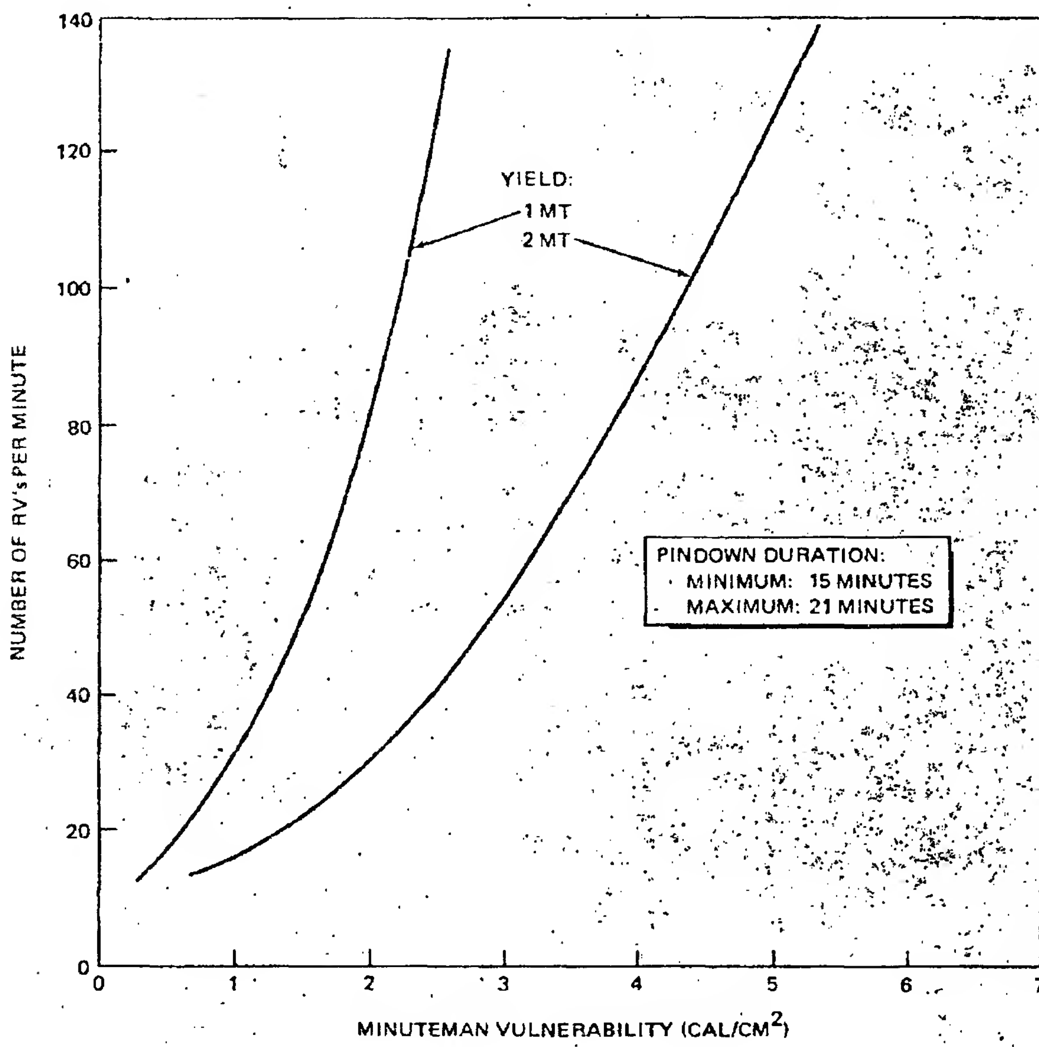

Figure 2-1 Minuteman Pindown Requirements (U)

can possibly kill more than a fixed number. This tactic is accomplished in the following way: at each wing, the duration of the pindown attack is divided by the total number of missiles to be launched; this factor yields the interval between successive launches. Launch sequence is uniformly random over the wing. Consider, for example, Wing I: assume 20 minutes of pindown, a 2-Mt SLBM warhead, and an assessed Minuteman hardness of 1 cal/cm^2. Under these conditions it takes Minuteman at least 50 seconds to transit the lethal volume generated by a single pindown burst. Because the Minutemen are launched 6 seconds apart (20 minutes divided by 200 missiles) 9 missiles at most are potentially vulnerable to the burst of an incoming RV. However, because the launch sequence is distributed uniformly over the entire wing, the likelihood is that no more than three of these will be within one lethal radius of a given burst.

The major result of the flyout tactic is that the number of surviving missiles is sensitive only to the number of attacking RV's. The attacker can do nothing to increase the number of missiles killed by any given RV.

Figure 2-2 plots the number of Minutemen saved by flyout as a function of the SLBM inventory which the Soviets devote to pindown. The secondary abscissa on the figure indicates the number of SSBN's the Soviets would require to have the associated pindown capability. The scale on this axis incorporates the following assumptions concerning SSBN availability and utilization:

A. No more than two-thirds of the force is on-station.

B. SLBM availability-reliability is 80%.

C. At least 50 time-sensitive targets will draw SLBM attack; these would include SAC bases and central command installations (Washington, D. C., NORAD Headquarters, etc.).

Figure 2-2 illustrates the folly of a pindown attack with an inventory that is not adequate to guarantee the results. The importance of this figure and the flyout strategy as a whole is not that the U. S. would <u>want</u> to employ such an option; rather, it is that it is wholly credible that the U. S. <u>could</u> employ such an option. Any nation planning a preemptive attack on the Minuteman must recognize this and accept the possibility that a preemptive strike against Minuteman may fail completely if not supported by an adequate pindown attack.

As a final point, recall that the requirements shown in Figure 2-2 are minimums and assume a larger-than-estimated SS-N-6 warhead and a Soviet planner banking on U. S. sure-safe levels as adequate for his kill. This weighs the game heavily in favor of the attacker. If, instead,

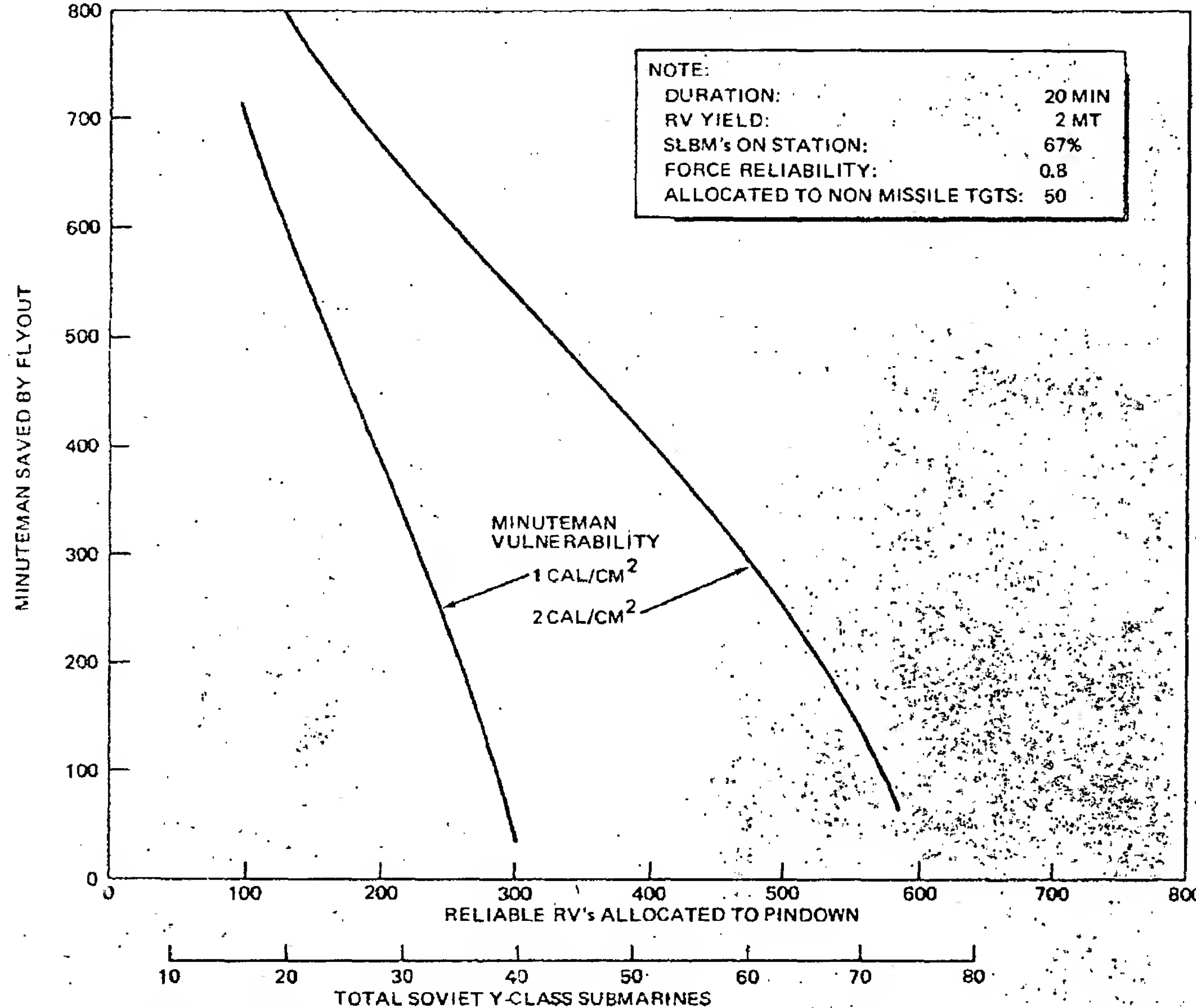

Figure 2-2 Minuteman Saved by Flyout (All Wings) (U)

one were to use moderately conservative assumptions (Soviet point of view), the requirements for an adequate pindown attack become impractically large. For example, if the Soviets assess Minuteman sure-kill hardness at 5 cal/cm^2 (which is not impossible or really even improbable), their pindown requirement is approximately 1,900 RV's to insure that no more than 30% of the Minuteman force survives flyout. Factoring in the availability and reliability of the SLBM's generates a requirement for 3,600 RV's or 225 ballistic missile submarines.

2.4 CONCLUSIONS

In conclusion, while the Soviets may have the capability to initiate pindown before the Minuteman can escape, they will not have the capability to mount an effective pindown attack for several years. Further, relatively modest improvements in Minuteman hardness levels (to 5 cal/cm^2) coupled with improvements in the Minuteman command and control sequence, designed to reduce the reaction time of the system (without compromising its fail-safe provisions), would render a pindown attack completely impractical.

There are two potential arms control agreements which could reduce the viability of a pindown attack significantly: an upper bound on SLBM deployment and a submarine stand-off limit. An upper bound on SLBM deployment would ease the requirements for Minuteman hardening. A submarine stand-off agreement (500 nmi or more) would eliminate the current Soviet SLBM as a pindown threat and would also provide the NCA with valuable and necessary decision time.

Section 3
PREEMPTIVE SCENARIOS

The credibility of a launch-on-warning (LOW) policy to a potential attacker is critically dependent on his assessment of the time required for the National Command Authority (NCA) to make the decision to respond. This assessment, in turn, is likely to be a function of the scenario, i.e., the events leading up to the attack and the nature of the attack itself: whether it is a surprise attack or the end result of a period of growing international tension. Three basic elements of preemptive nuclear exchange scenarios bear on the feasibility of LOW and the effectiveness of flyout under attack:

A. The amount of pre-attack alert.

B. The physical characteristics of the attack weapons.

C. The nature of the attack (e.g., massive attack, sneak attacks, etc.).

This section presents: (1) a discussion of the impact of alert status on the feasibility of LOW or flyout under attack, (2) a brief description of the forces available to the Soviet Union for the counterforce and pindown missions, together with an estimate of the potential effectiveness of those forces if the U.S. elects to ride-out the attack, and (3) a discussion of the attack options open to the Soviets and their validity for preemptive attacks.

3.1 ALERT STATUS

Literally thousands of scenarios have been formulated to investigate the likelihood of a nuclear exchange between the U.S. and USSR. They range from the sudden massive surprise attack with no strategic warning (often called a "blue-sky" attack) to attacks which occur only after extended periods of extreme tension, possibly coupled with some non-nuclear clashes. For many years U.S. strategic force procurement was based on maintaining an assured destruction capability in the event of a

"Blue-Sky" attack scenario featuring a sudden, all-out attack on the U.S. retaliatory forces.*

At the other extreme is the "graduated-response" scenario in which the initial nuclear blow is struck with a single weapon directed against a specific military target as a show of resolve.

The purpose of this section is not to investigate the credibility of the various scenarios, but rather to investigate the impact of the scenario on the feasibility of launch-on-warning and flyout under attack. For this purpose, only the alert level is crucial because that determines such key factors as:

A. Location and protection of key NCA personnel.

B. Willingness of NCA to respond to apparent attack on the basis of warning information.

C. The number of time-sensitive targets which must be destroyed by the attacker.

D. The concentration of U.S. ASW systems on the CONUS defense mission.

Undoubtedly, one of the major sources of a delay in initiating a response to an apparent nuclear attack would be the assembly of the NCA and the decision process it undergoes in such an environment, especially in the Blue-Sky scenario. Theoretically, the President is empowered to order a retaliatory strike; pragmatically, he would probably be unwilling to do so without consultation, especially because it is unlikely that he could be fully conversant with the retaliatory options available. Thus, it is probable he would defer a decision until he had a full understanding of the situation.

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*It is probable that a great many more considerations were brought to bear, but this is the scenario which was consistently used in Congress to justify strategic systems expenditures. Ironically, it is the same scenario which is given least credibility by most strategic analysts. They point to the high risk inherent in such an attack, the disastrous consequences of even partial failure, and ask what could possibly be gained by a nuclear strike that would be worth the risk. To make nuclear exchanges even remotely credible, these analysts postulate nuclear war as arising from a state of extreme tension characterized by recrimination, sabre rattling, and even major armed conflict in Europe or the Far East. Even then, nuclear war is either a last resort after all other options have been exhausted or comes about as a result of accident or misinterpretation of some action aggravated by the tension.

Another important potential source of delay is the passing of the command authority if the President is killed. The President's survival is far from assured; Washington, D.C. is vulnerable to attack by Soviet submarine-launched missiles and the warning time received in such an attack could be negligible. If the President is not already in a secure place--i.e., unless there has been adequate strategic warning--he must be considered vulnerable to surprise attack.

If the President should not survive or is not immediately available at the NCA, the assumption of his prerogatives by his designated successors is unlikely before his status is confirmed. Also, the same problem (i.e., being among the missing) may well exist with regard to the obvious successor.* Finally, the NCA must have some time to assess the situation and decide on the appropriate response.

It is unlikely that the NCA could assemble, review the situation, and authorize a retaliatory strike within the 10 minutes or less required for an SLBM to reach the Minuteman silo locations. Therefore, for consideration of launch-on-warning feasibility, we will restrict consideration to those scenarios involving a degree of strategic warning.

If a nuclear exchange arises as the result of a crisis in U.S./Soviet relations and, thus, is preceded by a period of heightened tension, most of the NCA-associated delays would disappear. When a crisis becomes sufficiently severe that the possibility of a nuclear exchange is raised, the NCA can be made secure, the options for retaliation can be reviewed, and a course of action can be determined. Then, if a strike actually occurs, the response time depends only on the time required to assimilate the strike news, decide on the option, and execute it. It is conceivable that these actions could be accomplished within the time of flight of Soviet SLBM's to Minuteman fields. Thus, LOW is at least potentially feasible if the attack occurs after a period of strategic warning.

Flyout under attack is not so clearly precluded by a surprise attack. There are two reasons for this. First, the time of flight for the Soviet counterforce-capable systems exceeds 30 minutes. Thus, the NCA would have considerably longer to respond than it does in implementing LOW. Second, as soon as any enemy weapon detonates on or over U.S. soil, many of the reservations concerning whether to retaliate vanish,

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*The United States maintains an alternate command post (Looking Glass) on continuous airborne alert. It is not clear under what circumstances this command post assumes control of U.S. strategic retaliatory forces, but it is almost certain that some delay is involved while the status of the NCA is determined.

especially because it can be shown (Subsection 3.3) that there are clear-cut distinctions between an accidental or unauthorized attack and one which is intended to destroy U.S. retaliatory capability.* Thus, the total time consumed by the NCA decision process may be reduced significantly.

3.2 POTENTIAL SOVIET PREEMPTIVE CAPABILITY

If, as appears possible, a moratorium on offensive weapon system deployment emerges from SALT, the limits on Soviet strategic force levels and capabilities over the next decade can be predicted with some confidence. Both the SS-9 and SS-11 appear likely to remain in the Soviet inventory--possibly in upgraded configurations. The older SS-7's and SS-8's should begin to pass from the scene; the reduction in numbers of strategic nuclear delivery vehicles (SNDV) would be offset by a growing SLBM inventory and possibly more SS-9's and SS-11's.

The Soviet SLBM inventory should continue to be comprised largely of the SS-N-6, although the Soviets are flight testing a more advanced missile (the SS-NX-8). No submarine large enough to accommodate this missile has been identified so its appearance as an operational system does not appear likely before 1974. Because the SS-NX-8 has considerably more capability than the SS-N-6--capability that would enhance significantly the effectiveness of the Soviet SLBM force--it is likely that this missile or some similar system will enter the Soviet inventory before the mid-1970's (References 1 and 2).

Table 3-1 summarizes the major characteristics of current Soviet systems which have potential utility in a preemptive strike. The potential results of a strenuous qualitative upgrade effort are also shown (References 1 and 3).

From the characteristics of the force shown in Table 3-1, it can be seen that SLBM's by themselves are not capable of the destruction of Minuteman silos. The combination of yield and accuracy is clearly inadequate. This mission must be performed by the Soviet land-based forces (and

*There are indications that SALT will produce an agreement between the U.S. and the Soviet Union to insure that accidental launch information is communicated immediately. In the event of an accident, it is in the best interest of the offending nation to honor such an agreement, especially during a crisis. There is no guarantee, of course, that a nation could not attempt to gain time by claiming that a deliberate attack was an accident. The numerical differences, however, between the largest conceivable accident and the smallest feasible prelude to a preemptive attack are so marked that it is doubtful that a lie could be made credible in this situation.

Table 3-1

CHARACTERISTICS OF SOVIET SYSTEMS
POSSESSING PREEMPTIVE STRIKE UTILITY (U)

Year System	Number	Payload Configuration (No. of Warheads/ Yield--Mt)	Range (nmi)	CEP (nmi)	Force Reliability
1971 SS-9	306	1/18	6,500	0.5	0.75
SS-11	970	1/1	5,500	0.8	0.75
SS-N-6	320*	1/2**	1,300	0.5 - 1.37***	0.65
1976 SS-9	306	3/5 or 6/2	5,400	0.5 0.25	0.9
SS-11	970	1/1.5	5,500	0.25	0.9
SS-N-6	448****	1/2**	1,300	0.5 - 0.7	0.8
SS-NX-8	384****	1/2**	3,000	0.4 - 0.6***	0.8

*Twelve boats were operational by May 1970; construction rate was 8 boats/year. There are 16 missiles per boat.

**Maximum yield consistent with estimated RV weight (1,500 lb). Current estimate is 1 Mt.

***Large uncertainty arises from submarine navigation estimates and azimuth error uncertainty.

****Assumes the Soviets begin to build a submarine compatible with the SS-NX-8 in 1972 and build to a construction rate of 8 boats/year from 1974 through 1976; also assumes that SS-N-6 boat construction halts with completion of those boats currently under construction. Soviets remain within SNDV limit by removing bombers and SS-7 and SS-8 missiles as submarines are deployed.

even these require extensive qualitative improvement). The Soviet ICBM forces, however, require at least 30 minutes of flight time to reach the northernmost Minuteman fields (Figure 3-1), while their SLBM's can reach the same areas in slightly more than 12 minutes. If the Soviet attempt a pindown attack, it is clearly a mission for the SLBM forces. The time of flight of the Soviet SLBM's could be diminished if the missiles were flown on depressed trajectories (Figure 3-2).

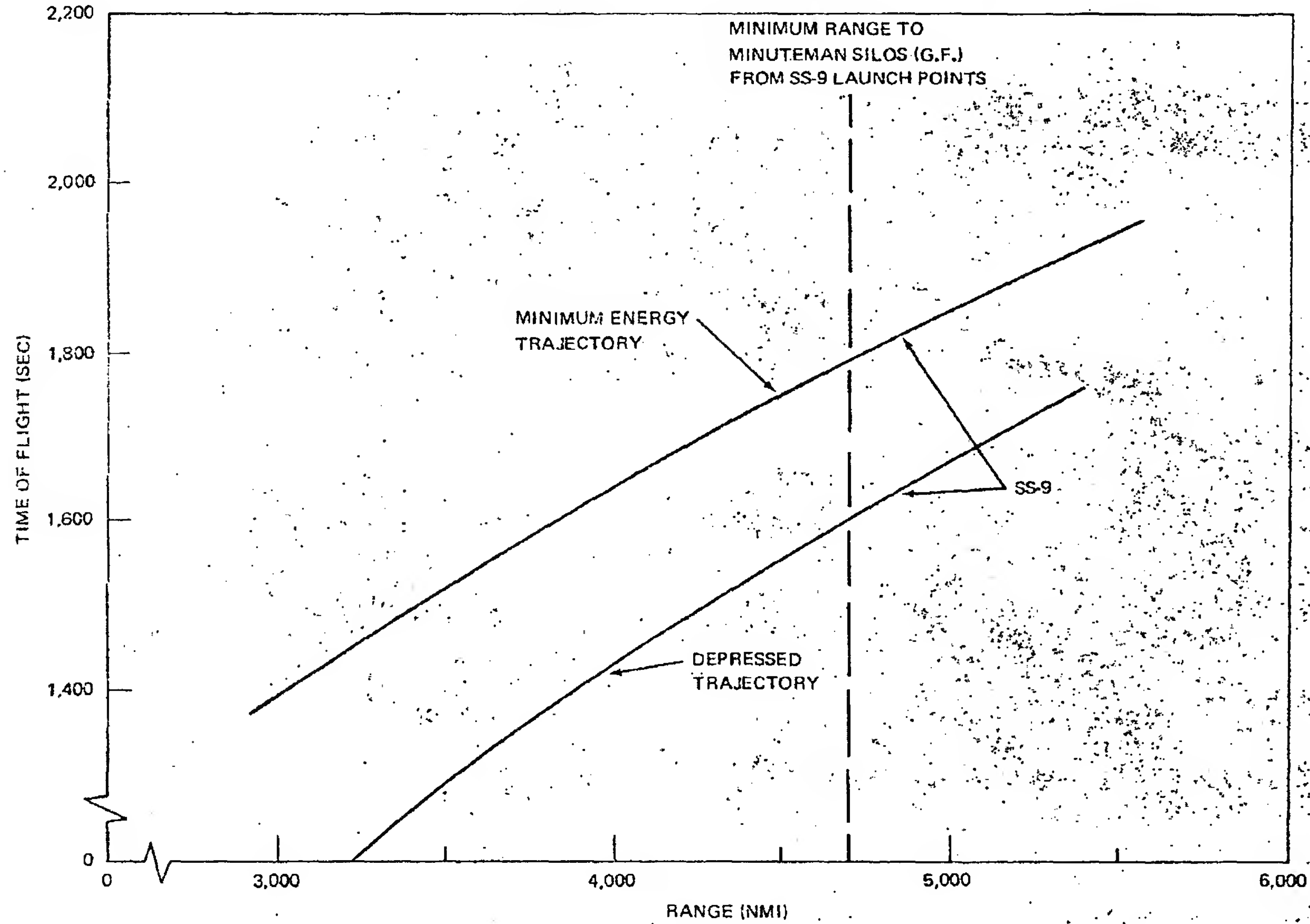

Figure 3-1 Soviet ICBM Time of Flight vs Range (NRE) (U)

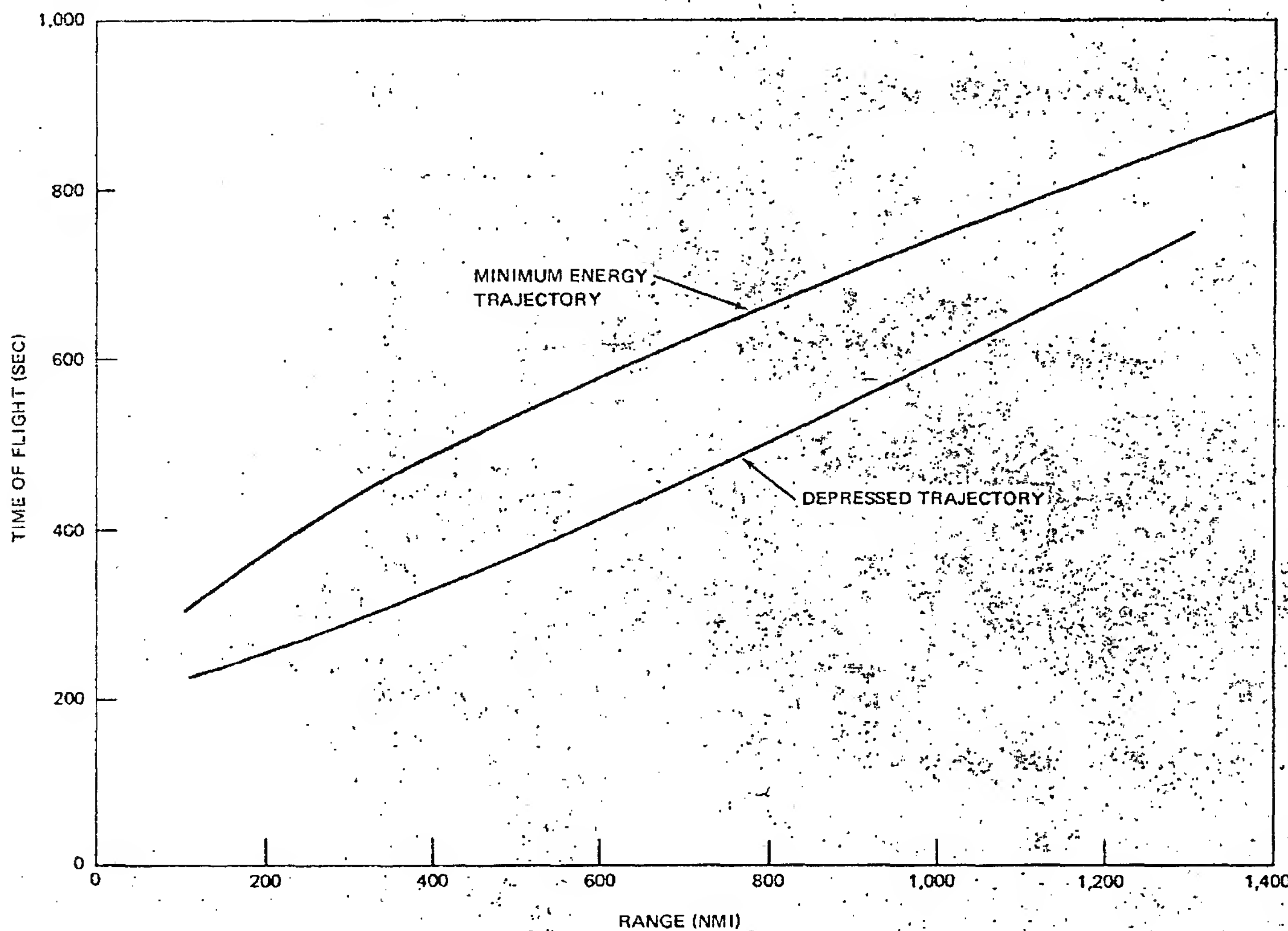

Figure 3-2 SS-N-6 Time of Flight vs Range (U)

The Soviets have not demonstrated a depressed trajectory capability with their SS-N-6 (i.e., they have not done the flight testing required). Also, estimated range of the SS-N-6 on a depressed trajectory is marginal to cover the north-central region, although it could probably cover most of the other regions. The SS-NX-8 should have adequate performance to reach any point in the U. S. on a depressed trajectory when it is deployed (circa 1973 to 1974) (References 2 and 4).

Table 3-2 shows the potential counterforce effectiveness of the current and 1976 Soviet threats if the United States elects, or is forced, to ride out a counterforce attack. Note that there is no appreciable counterforce threat at this time, but if the Soviets were to aggressively pursue MIRV's for the SS-9 and accuracy improvement for the SS-11 by 1976, 85% of the Minuteman silos could be destroyed by a successful counterforce strike. Even hardening the Minuteman silos (in this case, to approximately 1,000 psi) would not be adequate to meet the criteria of 300 survivable Minuteman vehicles (calculations based on data in References 5 and 6).

Soviet SLBM's, as well as their older ICBM's, were not used to attack the Minuteman silos in this evaluation--first, because they are not required; second, because they possess only limited capability; and third, because there are missions to which the SLBM's at least are better suited (viz, destruction of relatively soft, time-sensitive targets and pindown of the Minuteman).

3.3 PREEMPTIVE ATTACK STRATEGIES

The natural reluctance of the NCA to adopt a LOW policy is enhanced by concern that an accidental or unauthorized attack would trigger a massive retaliatory strike which, in turn, would cause a retaliatory attack on the United States. To avoid such an exchange, it has been suggested that a threshold attack size be adopted. Then, such a threshold must be exceeded before a retaliatory attack would be launched. Critics of the threshold concept argue that an astute opponent could disguise the early stages of an attack--staying below the threshold--while sending in enough missiles to pin down Minuteman so that LOW is not possible. This subsection examines the potential viability of disguised attacks as a means for denying LOW capability.

The requirement for and potential effectiveness of a disguised attack depends to a great extent on the alert status. If there has been no period of strategic warning, attacking with less than full force only serves to give those systems not attacked in the first wave a measure of warning. In particular, the national command centers should be attacked as early as possible. Further, any SAC bomber base not attacked immediately will be able to launch bombers until it runs out of planes or is destroyed. Thus, at least 50 targets must be assaulted in the first few minutes of

Table 3-2

POTENTIAL SOVIET COUNTERFORCE EFFECTIVENESS
UNDER OFFENSIVE SYSTEM DEPLOYMENT MORATORIUM (U)

Force Level	306 SS-9		970 SS-11			
Configuration (No. of RV's and Yield)	1 at 18 Mt	3 at 5 Mt	1 at 1 Mt	1 at 1.5 Mt	Both Systems; Optimized Attack	
Year	1971	1976	1971	1976	1971	1976
CEP (nmi)	0.5	0.5	0.8	0.25		
PK_{SS}(36P5)	0.9	0.66	0.11	0.77		
No. of Silos Destroyed (36P5, 1,000 Total)*	243	535	96	672	315	849/865**
PK_{SS}(42P6)	0.76	0.46	0.64			
No. of Silos Destroyed (42P6, 1,000 Total)*	205	372	52	559	247	725/746**

*Assumes 0.9 reliability.
**Without/with reprogramming for reliability.

the engagement if the bombers are to be destroyed on the ground. Because the bomber bases must be attacked from both the Atlantic and the Pacific, the likelihood of such an attack being construed as either unauthorized or accidental is negligible.

If there has been a period of strategic alert, some of these arguments are weakened. In such a situation, the opponent has no chance to destroy much of the bomber force because it will be on airborne alert. Also, the NCA undoubtedly will be secure. Thus, a disguised attack during a period of strategic alert could be restricted to Minuteman fields only without seriously affecting the outcome of the attack.

However, the credibility of a disguised attack, even against the Minuteman, is open to question. The lethal radius of a single weapon (except an SS-9) is not large enough to pin down an entire Minuteman wing, even briefly; thus, any attempt to pin down the Minuteman will require multiple bursts on each wing. (It is shown in Section 5 that 13 two-megaton warheads are required just to cover the flyout corridors from the Minuteman wings for an instant.) Further, the aimpoints of these bursts and the coordination of the launches (more than one submarine would be required) will unambiguously define the attack as the initiation of a pindown attempt. If the attack is a pindown attempt, successive waves must follow within one to two minutes; otherwise, pindown is not assured.

With a boost-phase detection system, the second wave would be detected about a minute after launch, less than three minutes after the first wave was launched, and approximately 8 (if SLBM) to 25 (if ICBM) minutes before impact. Also, if pindown duration is to be a reasonable length, the ICBM attack must be launched as soon as the pindown attack is launched. Thus, the U. S. warning system would see attacks from several locations (from both ICBM's and SLBM's) almost immediately or the attack will be ineffectual. Thus, the nature of any pindown attack attempted must be clear long before burst of the first warhead.

A second indicator of the nature of the strike can come from the weapons employed--ICBM, SLBM, or both. The probability that both ICBM's and SLBM's would be involved in an accidental or unauthorized strike is miniscule. On the other hand, a preemptive strike which involved SLBM's only or ICBM's only would be equally unlikely. If SLBM's are to be used to pin down the Minuteman, any delay in launching the silo-busting ICBM's prolongs the pindown duration, thus increasing demands on the SLBM inventory. If no pindown is attempted, the Minuteman can be flown out any time. If the first wave of the attack is small enough to be considered an accidental or unauthorized launch and not immediately followed by a second wave, the U. S. can afford to ride it out and determine the proper reciprocal action. If the first wave is an attempt at pindown, the succeeding attack must follow immediately; hence the U. S. will once again have ample warning.

In summary, it would appear that the most conservative assessment of Soviet capability to deny launch-on-warning to the U.S. is to assume an all-out attack using SLBM's directed against SAC bases and command centers, and for Minuteman pindown. Assessments of LOW feasibility in this report will focus on this attack.

Section 4
LAUNCH-ON-WARNING

For the purpose of discussion, a convenient, if artificial, distinction is made in this report between launch-on-warning (LOW) and flyout during attack. In this context LOW refers to the capability to launch at least some portion of the ICBM force before a pindown attack could begin; flyout during attack refers to a launch doctrine that calls for launching Minuteman after some SLBM RV's have burst but before the brunt of the ICBM attack arrives (this doctrine involves accepting some damage from the pindown environment while exploiting windows in the pindown coverage). This section discusses the issues bearing on the technical feasibility of LOW.

There are four critical time intervals bearing on the feasibility of LOW:

A. The time required for the attacking missiles to reach the Minuteman installations.

B. The time delay between launch of the attack and warning of the attack (i.e., the warning arrives at the National Military Command Center [NMCC]).

C. The time required by the NCA to assimilate the warning and decide to launch the Minuteman force.

D. The time required to code, transmit, decode, verify, and execute the launch command, and for the missiles to fly out a safe distance.

This section discusses each of the intervals and the doctrine and system limitations which result in the delays. Then, several preemptive attack scenarios are examined to determine the feasibility of LOW, both now and in the foreseeable future.

4.1 ATTACK FLIGHT TIME REQUIREMENTS

To some degree, LOW is a misnomer because undoubtely there will be bursts on coastal, time-sensitive targets long before the Minuteman can get away. In particular, the enemy is certain to attempt to disrupt the NCA by destroying Washington, D.C. This can be accomplished

with little or no warning and would tend to confuse the command and control process. Thus, the decision to launch Minuteman may be made after physical damage has been sustained to the U.S. from nuclear bursts. However, these issues bear on policy, not on physical limitations of the system. The point made here is that the warning on which the decision to launch is based will probably include actual bursts on or over U.S. territory.

A preemptive planner can be expected to put a premium on a number of time-sensitive targets in the U.S. These include the NCA, the alternate command posts, NORAD headquarters and, of course, all SAC bases with bombers and tankers. The number of SAC bases fluctuates. In Reference 4, 55 bases were identified and this number is used in this report. The Air Force may reduce this number for economic reasons; however, the number could increase drastically during a strategic alert.

The 55 SAC targets identified in Reference 4 are assigned in Figure 4-1 to regions based on the probable direction from which an SLBM attack would emanate. Also shown on the map are the six Minuteman wings and the three Titan deployment regions. The three arcs on the map represent approximately equal distances from possible Soviet SLBM launch points in the Atlantic and Pacific Oceans, the Gulf of Mexico, and Hudson Bay. The targets in the north-central regions are about equally distant from all three launch areas and from Hudson Bay. The numbers in each region indicate the time of flight for nominal and depressed trajectory SLBM flights from the corresponding launch region.* Note that the maximum time required for an attacker to begin a pindown attack is about 14 minutes and that length of time applies only at the northernmost wings. Pindown at Whiteman Air Force Base could begin as early as 8 minutes after launch.

4.2 U.S. WARNING SYSTEMS AND DELAY TIMES

The U.S. has three operational strategic early-warning systems and a fourth system in the early stages of deployment. When the fourth system is fully operational, the U.S. will have redundant coverage of missiles launched in the Soviet Union or in the Atlantic or Pacific Oceans north of the Equator commencing less than a minute after the missile is launched. Performance data on these systems is summarized in Table 4-1. The four systems are:

A. The Ballistic Missile Early-Warning System (BMEWS, 474L)--a string of radars located in England, Greenland, and Alaska.

*Actually, pindown bursts will take place at fairly high altitudes; thus, time of flight shown is from launch to a reentry altitude of 25 nmi.

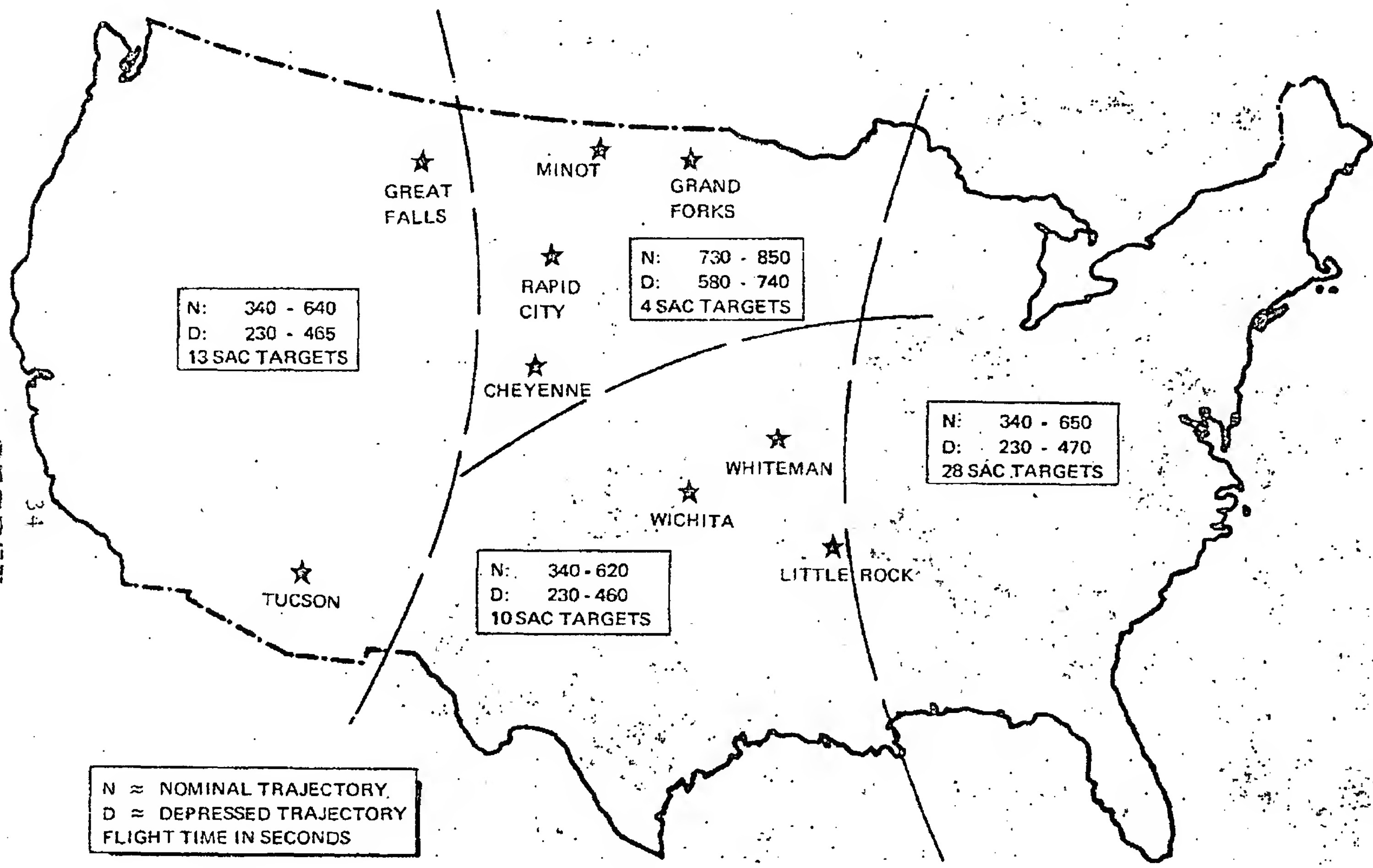

Figure 4-1 Soviet SLBM Time of Flight to SAC Targets (U)

Table 4-1

EARLY WARNING SYSTEM PERFORMANCE (U)

System	Time of Detection (Secs After Launch)	Time of NMCC and NORAD Alert (Secs After Launch)	Probability of Detection (Single Launch)	Probability of Detection (Mass Launch)	False Alarm Rate
474L (BMEWS)		700 to 900	0.99	1.0	1 per 7 years
440L (OTHF)	<100	400[1]		1.0	1 per 6 months
474N (SLBM Net)	150	200[2, 3]	0.5	0.96	?
Boost-Phase Detection Satellite[4]	55 to 75	85 to 105		1.0	?

(1) Five minutes of data processing required to determine detection.
(2) 350-nmi trajectory.
(3) SS-N-6 can overfly most of the 474N radar net in attacks on coastal targets.
(4) Not fully operational.

B. The anti-SLBM warning system (called 474N)--a netting of converted SAGE air defense radars and the FPS-85 radar at Eglin Air Force Base in Florida, designed to detect submarine-launched ballistic and cruise missiles.

C. The forward-scatter over the horizon radar system (OTHF--designated 440L)--with receivers spread from Great Britain to the Mediterranean and transmitters in the Western Pacific.

D. Boost-phase tracking system--satellite-based warning system which will cover both the interior of the Soviet Union and feasible SLBM launch areas when fully operational.

The BMEWS system is the oldest of the U. S. strategic warning systems. Construction on this system of northward-looking radars began in 1958, and the system was completed in 1966. BMEWS would provide warning information to NORAD headquarters of a Soviet ICBM attack on the United States between 12 and 15 minutes after launch of the attack. A multiple-detection requirement insures that the false alarm rate is extremely low--estimated to be no more than one in seven years. There have been no false alarms since BMEWS has become fully operational. Probability of detection of a single ICBM by BMEWS is 0. 99; detection of an attack by more than one missile is assured (Reference 5).

The 474N SLBM warning system was developed as an interim system to provide some warning against submarine-launched threats. Most of the radars in the system are modified SAGE-system radars with extremely limited range against ballistic missiles. As a result, the newest Soviet SLBM (the SS-N-6) can over-fly most of the 474N system.* Against systems which are launched in the radars' field of view, warning would reach NORAD about 200 seconds after launch. Probability of detection of a single launch is no better than 0. 5, even when the missile is launched in an area that is covered by the system. Detection of large attacks (five or more missiles), however, is virtually certain (Reference 5).

The 440L forward-scatter OTH system reached IOC in 1968, but full operational capability was not achieved for an additional two years and work is continuing on improving the system's data-processing capability. The 440L system detects a missile as it penetrates the ionosphere (typically within 100 seconds after launch), but warning may not reach NORAD until up to five minutes later because of the data processing required to verify detection. The current 440L systems

*In trajectories into coastal targets only. SS-N-6 could not overfly 474N on a trajectory to any of the Minuteman wings.

cover launches in the Soviet Union; OTH detection of launches involving more than one missile is virtually assured (Ref. 5).

The three operational early-warning systems described above leave serious gaps which could be exploited by an attacker. Most serious of these is the lack of adequate SLBM warning. It is quite conceivable that an SLBM attack could arrive at many U. S. targets with no warning whatsoever. Particularly vulnerable are targets near the sea coasts (i. e., the National Command Authority in Washington, D. C. and about 70% of the U. S. population).

To remedy the SLBM problem and to provide more thorough and rapid coverage of the Soviet Union, the U. S. is deploying a satellite-based, boost-phase detection system. When operational, this system will provide warning to NORAD and to the NMCC of missile launches (ICBM or SLBM) within 1-1/2 to 2 minutes after launch. The false-alarm rate is expected to be very low and detection of multiple launches is certain. This system should be fully operational by 1973, at the latest (Ref. 4).

When the boost-phase detection system becomes operational, the U. S. will have redundant coverage of the potential ICBM and SLBM launch points. More important, the systems and the phenomena observed by each system are independent of one another; thus, the likelihood of a false alarm registering on more than one system is virtually zero. Also, the likelihood of simultaneous failure of two systems is equally remote. Thus, the U. S. will be assured of reliable warning of a Soviet attack no later than six minutes after launch and will have a high probability of warning within two minutes of launch. More important, the Soviet planner must assume all warning systems are functioning; therefore, he will not be able to count on masking his intent for more than one to two minutes.

In summary, currently many critical targets and much of the population of the United States are subject to attack without warning. Much of this vulnerability will be eliminated within the near future and warning will be received, with high probability, within two minutes of launch. For the most part, the systems which comprise the U. S. early-warning capability have low false-alarm rates and high reliability when considered independently. Taken altogether, the early-warning systems should insure that no launch could ever occur as the result of a false alarm if a launch-on-warning policy were implemented.

4.3 U. S. STRATEGIC COMMAND AND CONTROL

The third area to be examined to determine U. S. LOW capability is the operation of the NCA in reaching a launch decision and the execution of the launch command. Figure 4-2 is an idealized representation of the

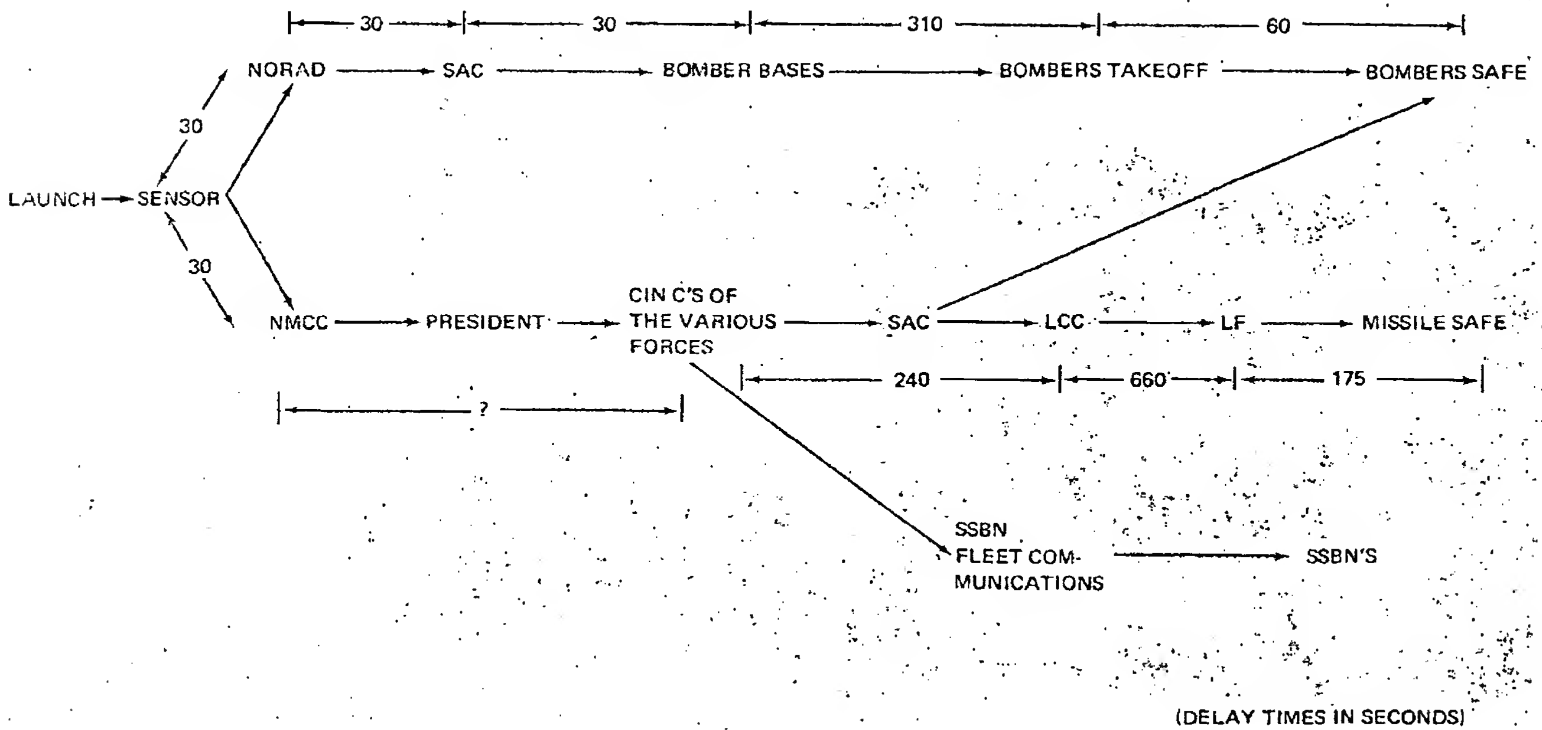

Figure 4-2 National Command-Warning to Response Cycle (U)

U. S. strategic system warning-to-response command linkage showing the approximate time required to complete each link. The upper line in Figure 4-2 shows the flow of information leading to the SAC bomber force. Because bombers are recallable, NCA approval is not required prior to bomber takeoff. The lower line in Figure 4-2 shows the principal elements of the chain of command leading to Minuteman launch.

In the missile-command loop, major uncertainty in the time required to complete the chain arises from the impossibility of predicting the reaction time of the NCA. It is not really even possible to assign upper and lower bounds to this interval. Even if the NCA is assembled and a response plan is already selected, some time would be required to assimilate the nature of the attack. On the other hand, if the attack is a complete surprise and Washington, D. C. is attacked early in the exchange, just assembling the NCA, or what is left of it, may consume hours. Because any assessment of this time interval necessarily must be extremely scenario dependent, this study adopted the approach of determining how much time could be allotted to this process given the probable attack parameters and the known time delays.

Once the launch decision has been made at the NCA level, there are still three significant delays before the missiles can be considered safe.* The most important and the most surprising of the delays is the 11 minutes required by the launch control crew to receive, decode, authenticate and execute the launch command. This time delay is not a minimum or even the average of all launch crews but rather it is an interval which has been established by Air Force doctrine to insure that no crew attempts to launch before all crews have completed their prelaunch functions.

There are two reasons why this interval is determined by the slowest crew. The first results from a fail-safe mechanism built into the Minuteman control. Within each squadron (50 missiles and 5 launch control centers [LCC]) the LCC's are interconnected so that any LCC can cancel a launch command issued by any other LCC. Thus, if even one crew in a squadron has not completed processing of the launch command it can (and must) cancel any other crew's command. The second reason results from the requirement for a common time reference for all the missiles. This common reference is required in

*In this case, third-stage cutoff is used as the time at which the missile is safe. Minuteman III actually remains vulnerable beyond this time because its guidance and post-boost propulsion system remain active; however, it is more than 60 nmi downrange from the launch point and at 110 nmi altitude. It will be shown in Section 5 that extending a pin-down attack to cover the region of post-boost propulsion system operations is impractical.

order that the coordination built into the missile targeting can be accomplished; this, in turn, is required to avoid fratricide at multiply-targeted aimpoints and to insure proper sequencing of RV's which are attacking defense units, etc. It is understood that at one time this interval was fixed at six minutes but some crews were incapable of meeting this standard. The 11-minute delay in the launch control center, together with the four minutes required to process code and transmit the launch command, mean that 15 minutes are required to get Minuteman out of their holes after the decision to launch is made.

4.4 FEASIBILITY OF LAUNCH-ON-WARNING

Table 4-2 shows how the Minuteman response time compares with Soviet SLBM time of flight to the various Minuteman wings. Four different cases which could arise over the next few years are considered. This table assumes that no time is consumed by the NCA decision process.

Current U. S. and Soviet capabilities are shown in the first row of Table 4-2. This case assumes that the U. S. does not yet have a satellite-based, early-warning system over the SLBM launch areas and restricts the Soviet Union to nominal trajectories. Even so, the Minuteman clearly cannot escape before the first Soviet missiles arrive.

The other three lines of Table 4-2 represent hypothetical situations which could be possible in the time periods indicated. By 1973, the U. S. will have a boost-phase warning capability in the SLBM launch regions. This will effect considerable saving in time to launch Minuteman, but the saving is not adequate to insure Minuteman launch before the SLBM could arrive. In addition, the improvement could be offset by Soviet development of a depressed-trajectory threat. It might also be possible by 1973, or thereafter, for the U. S. to improve Minuteman launch-crew capability to meet the original standard of six minutes from receipt of command to execution. If this could be done or if an equivalent length of time could be saved in some other way, and the Soviets do not develop a depressed trajectory threat, a launch-on-warning capability would be marginal, given the highly optimistic assumption that the NCA is ready to react instantaneously. Once again, however, a depressed-trajectory threat would be adequate to remove such a capability.

The only way it appears possible to guarantee that Minuteman could fly out to safety would be for the U. S. to enforce, either through agreement or by ASW capability, a Soviet submarine standoff from our shores of at least 500 miles. This would put the north-central Minuteman wings out of range of the SS-N-6 on a depressed trajectory. If the Soviets deploy the SS-NX-8, its depressed trajectory capability would not be

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Table 4-2

FEASIBILITY OF EVADING PINDOWN (U)
(Attack Starts at T = 0; All Units in Seconds)
Strategic Alert

Time Period	SLBM Time of Flight		Earliest Possible Minuteman Launch Time	Earliest Time to Safety
	Wings II, III, V, & VI	Wings I & IV		
Curent	730 - 850	600	1, 100	1, 275
1973 - 1976	580* - 740*	450*	985**	1, 160
1973 - 1976	580* - 740*	450*	685***	860
1975 - 1980	910* - 1, 020****	700*	685	860

*Depressed trajectory threat.
**Boost phase warning system.
***Improved launch crew facility.
****Submarine standoff (500 nmi) SS-NX-8.

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adequate to threaten the Minuteman's LOW capability. Such a standoff would provide the NCA with some time (albeit only two minutes) to make a decision.

Because the NCA cannot react instantaneously, it appears that getting Minuteman out of the ground before a pindown attack could be initiated is not possible as long as the Minuteman command and control structure remains in its current form. Detailed information about the Minuteman command and control structure was not available to this study; therefore, it is not possible to make specific recommendations about how this system might be improved or, indeed, even to speculate how great that improvement could be. Instead, this study will investigate in Section 5 the possibility of flying Minuteman out of the holes even though an attack has begun.

Note that a Soviet planner is unlikely to have detailed insight into U.S. command and control delays. His assessment of U.S. response time is likely to be predicated principally on his experience with his own system; it may be either smaller or greater than the actual delay in the U.S. system. Consequently, the above discussions do not necessarily indicate that a Soviet planner would be willing to discount a LOW threat, especially in a strategic alert situation.

Section 5

FLYOUT UNDER ATTACK

From the Soviet planner's point of view, it is unlikely to be sufficient to merely have the capability to initiate a pindown attack before the Minutemen are out of their silos; he must also have sufficient missile inventory and the ability to coordinate the use of that inventory to insure that the Minutemen remain bottled up long enough for his ICBM's to arrive. In this section the inventory required to guarantee that the Minutemen are pinned down is calculated as a function of the hardness level of the Minuteman and the yield of the Soviet warheads. Then, the risk associated with flying out through a pindown attack which is deficient in inventory is examined to determine at what Soviet SLBM inventory levels flyout and rideout become equally attractive alternatives (from the viewpoint of equal numbers of survivors).

5.1 THE PINDOWN ENVIRONMENT

The ideal pindown technique would be to create such a severe environment over the ICBM launch facilities that any missile attempting to fly out would be destroyed. At the same time, the nuclear environment must permit the incoming, silo-killing RV's to penetrate to their targets without risk. Such an environment appears feasible because missiles normally are far more vulnerable during boost to most of the lethal effects of a nuclear burst than are their reentering RV's.

The major problem with maintaining a lethal environment over the launch areas is the lack of persistance of most lethal effects from a nuclear burst. As Figure 5-1 shows, many of the lethal effects from a nuclear burst extend over large areas, but their persistance is measured in small fractions of a second; only dust provides a long-duration hostile environment.

Dust is hardly a satisfactory pindown agent--the lethal radius is relatively small, and it is the one mechanism that is more dangerous to an incoming RV than it is to a missile flying out. The reason for the latter is the velocity difference between the two objects during their transit through the dust cloud: the missile is accelerating from rest and the RV is near its maximum speed. Because damage from dust collision varies with the kinetic energy of the object and, thus, increases with the square of the velocity, the environment is 16 to 30 times more lethal

Figure 5-1 Minuteman II Boost Phase Vulnerability (1 MT Weapon) (U)

to the RV than to the ascending missile. Further, the attacker has no way of determining when the environment has cleared sufficiently to allow his RV's to penetrate. On the other hand, the nation under attack has (at least potentially) the means to sample the environment and the dust will permit flyout long before any incoming RV would have a chance to penetrate.

An alternative to creating a lasting lethal environment is to renew it at frequent intervals so that any missile trying to fly out will be within one lethal radius of a burst at some time during boost. To minimize the number of RV's required, it is desirable to work in the altitude regime where the lethality of the warhead is most severe. From Figure 5-1 we can see that this means detonation at altitudes of 25 nmi or more and reliance on x-rays as the principal kill mechanism.

5.2 MINUTEMAN VULNERABILITY

The lethality contour shown in Figure 5-1 is for an x-ray fluence of 1 cal/cm^2. This is the assessed sure-safe hardness of the Minuteman III system. Minuteman II is actually assessed to be somewhat more vulnerable (about 0.75 cal/cm^2). From the standpoint of this study, the actual sure-safe hardness of Minuteman is less important than the value the Soviet planner might assign to the hardness. Because Minuteman vulnerability is most critical in the area of electronics, Soviet intelligence about this number is not likely to be very good. Further, the difference between the sure-safe number quoted above and the sure-kill that a preemptive planner is likely to require is considerable. Sure-kill levels may be from 2 to 10 times as high as the sure-safe number. The lethal mechanisms created by a nuclear burst in and out of the atmosphere and their effect on Minuteman subsystems are discussed in some detail in Appendixes A and B.

Because it would be virtually impossible to determine a Soviet planner's assessment of Minuteman hardness, this study has treated the pindown problem parametrically and has examined Soviet pindown requirements for Minuteman vulnerabilities from 1 to 10 cal/cm^2. An example has been selected to illustrate the method. In this example, the Soviet SLBM RV yield is assumed to be 2 Mt and the Minuteman vulnerability is set at 1 cal/cm^2. The reader should recall, however, that this is merely an example and, in some sense, it represents the lower bound on Soviet requirements rather than an expected value which undoubtedly would be much higher..

5.3 SOVIET REQUIREMENTS TO GUARANTEE PINDOWN

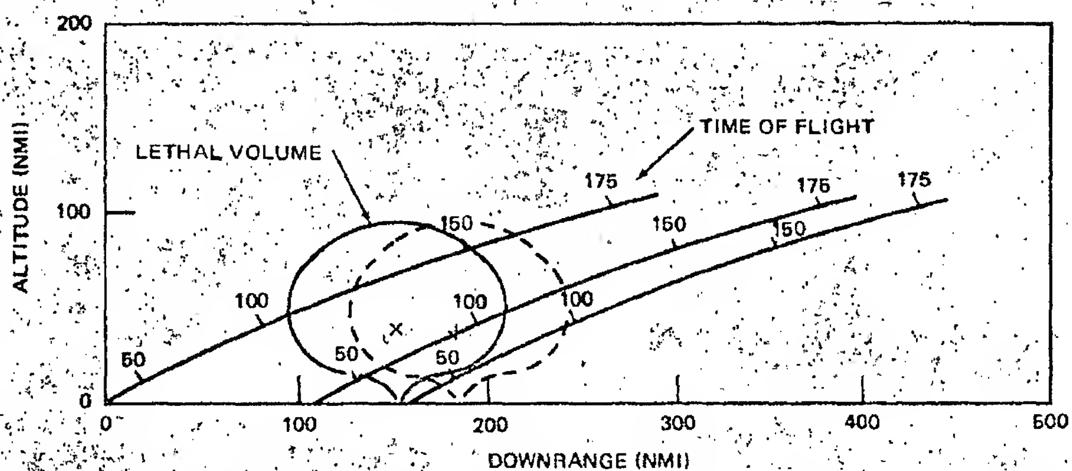
It is has been argued that the precise number of weapons required to guarantee the pindown of the Minuteman is really unimportant because if any weapons were detonated over the Minuteman fields, the

uncertainty of Minuteman survival through boost would be sufficient to keep Minuteman missiles in their silos. This argument ignores the likelihood that a preemptive attack would not be attempted if the attacker were not confident of his ability to destroy most of the Minuteman silos. It also ignores a viable Minuteman flyout strategy--one which can guarantee some level of Minuteman survivability in the face of a deficient pindown attack. This strategy will be described in Subsection 5.4; first, however, the requirements to guarantee that Minuteman is pinned-down will be calculated.

Figure 5-2 illustrates both the pindown problem and the manner in which the pindown requirements were ascertained. The bottom part of Figure 5-2 represents the region covered by Wing I of the Minuteman force (the actual deployment is shown in Figure 5-3). The top part of the figure shows side views of Minuteman trajectories with time marks indicated. The trajectories shown coincide with launch points located at the extreme northern and southern boundaries of Wing I.

The pindown problem may be stated in the following manner: the attacker assumes that his opponent knows the precise nature of his attack and can exploit any weakness; for this reason he must deny any launch window to the pinned-down force. Therefore, he must insure that any missile flying out will be within a lethal radius of one of his weapons at some point during the boost phase. Notice that it is not sufficient or even desirable to detonate weapons over the wing itself; pindown bursts should be downrange of the wing in the threat tube subtended by the Soviet target structure. The USSR subtends a rather large angle from U.S. Minuteman fields. For the purpose of this study it was assumed that the Soviet planner would consider it adequate to pin down Minuteman aimed at the most valuable part of the Soviet Union and would accept some damage in the eastern regions. Consequently, the angle shown in Figure 5-2 covers only that part of the Soviet Union west of 75° E. Longitude.

The guaranteed pindown solution was determined for Wing I geometrically from Figure 5-2. The solution is bounded by two considerations: the location of the pindown bursts must be far enough downrange from the launch emplacements to insure that missiles from the northern-most launch facilities do not escape under the lethal region, but at the same time the burst points must be as close to the deployment area as possible to minimize the width of the threat tube. Also, it is desirable to keep the burst close to the wing in order to operate where the ascending missile is still traveling fairly slowly. From the top part of Figure 5-2, we can see that the time required for Minuteman to traverse the lethal volume generated by a burst is affected strongly by the downrange distance of the burst from the launch point. Consequently, to maximize the interval between bursts, the burst points must be as close to the wing as possible.



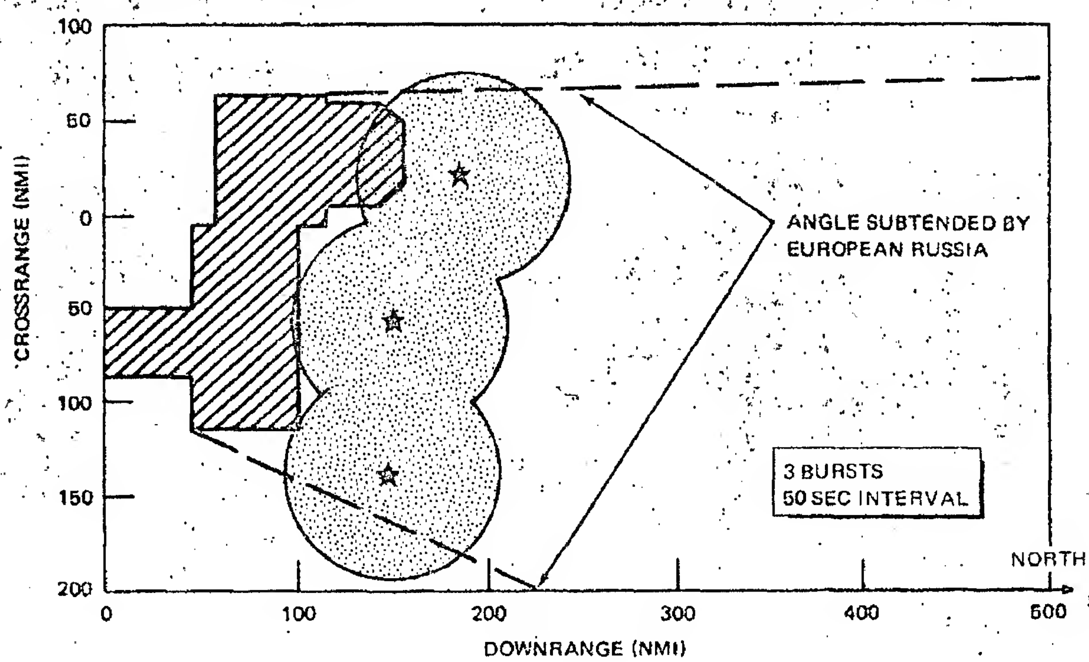


Figure 5-2 Pindown Geometry—Wing I ; 2 MT Weapon , 1 Cal/Cm^2 (U)

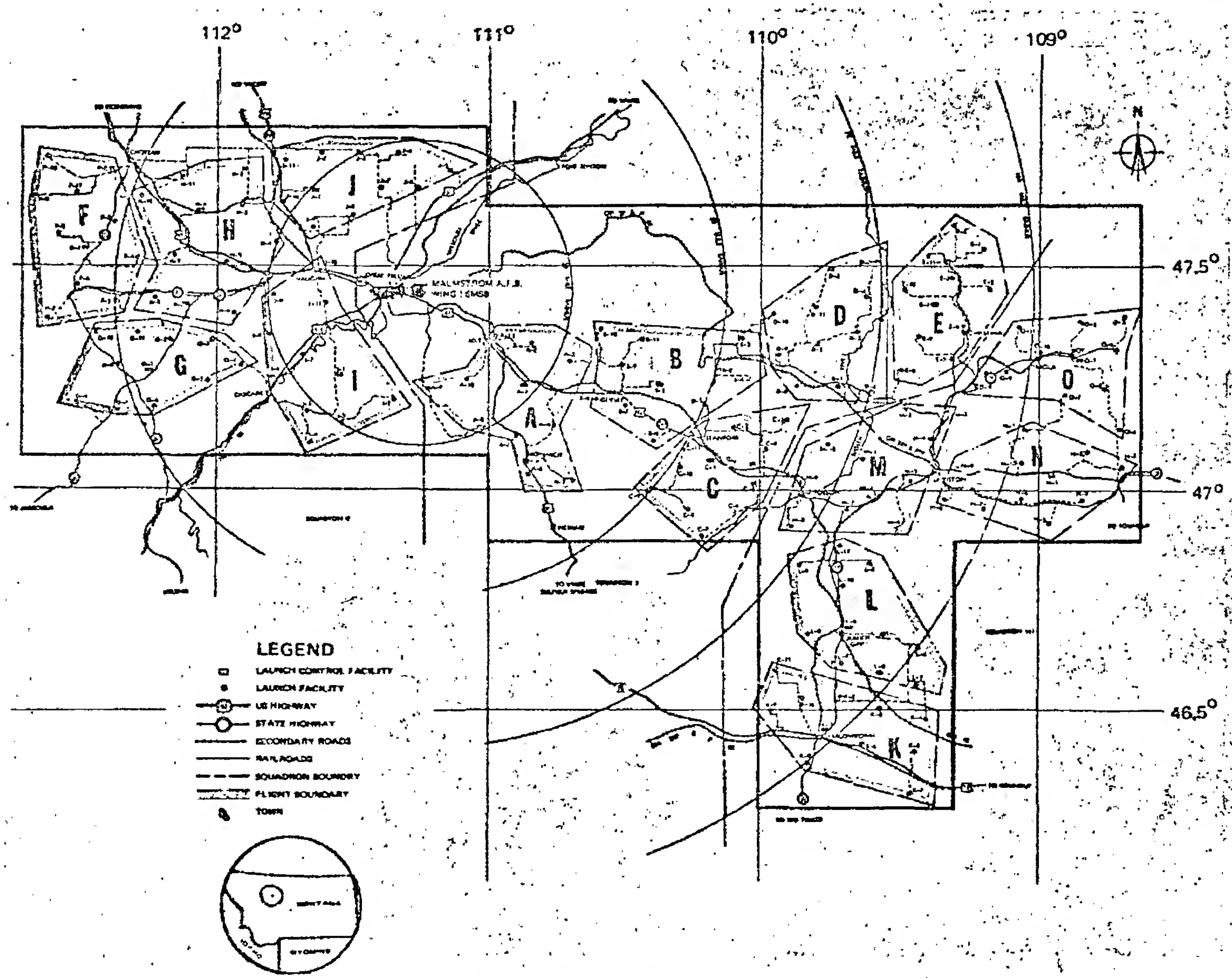


Figure 5-3 Wing I, Malmstrom AFB (U)

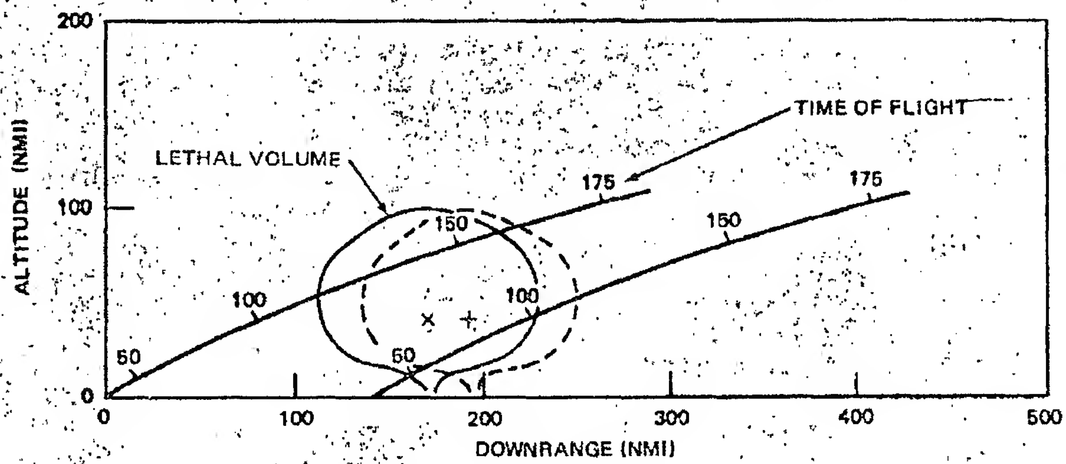
The locations shown in the bottom part of Figure 5-2 are nearly optimal for Wing I. Note that Minuteman requires at least 50 seconds to traverse the lethal volume generated by these burst points regardless of the location in the wing from which the Minuteman is launched. This determines the frequency with which the pindown burst must be repeated. In this case, the three bursts required to cover the width of the threat tube must be repeated every 50 seconds to insure that no Minuteman could escape.

Pindown requirement varies from wing to wing because it is sensitive to the geometry of the wing. A wing which is wide from east to west, such as Wing I, requires more bursts to cover the threat tube than one which is narrow, such as Wing VI (Figure 5-4). However, Wing VI is long in the north-south direction and, therefore, the bursts must be repeated more frequently because a missile launched from the southern-most part of the wing can traverse the lethal volume generated by the burst in 40 seconds. Wings II through V have approximately the same overall geometric configuration and require identical pindown attacks (two bursts every 50 seconds). Table 5-1 summarizes the guaranteed-pindown requirements for all the wings under the conditions assumed for the example.

Table 5-1

SOVIET MINIMUM GUARANTEED PINDOWN REQUIREMENT (U)

Wing	Number of Bursts	Interval Between Bursts	Maximum Pindown Duration	Number of RV's Required
I	3	50	20	72
II	2	50	20	48
III	2	50	20	48
IV	2	50	22	52
V	2	50	20	48
VI	2	40	20	60
SLBM Yield = 2 Mt. Minuteman Vulnerability 1 cal/cm^2				



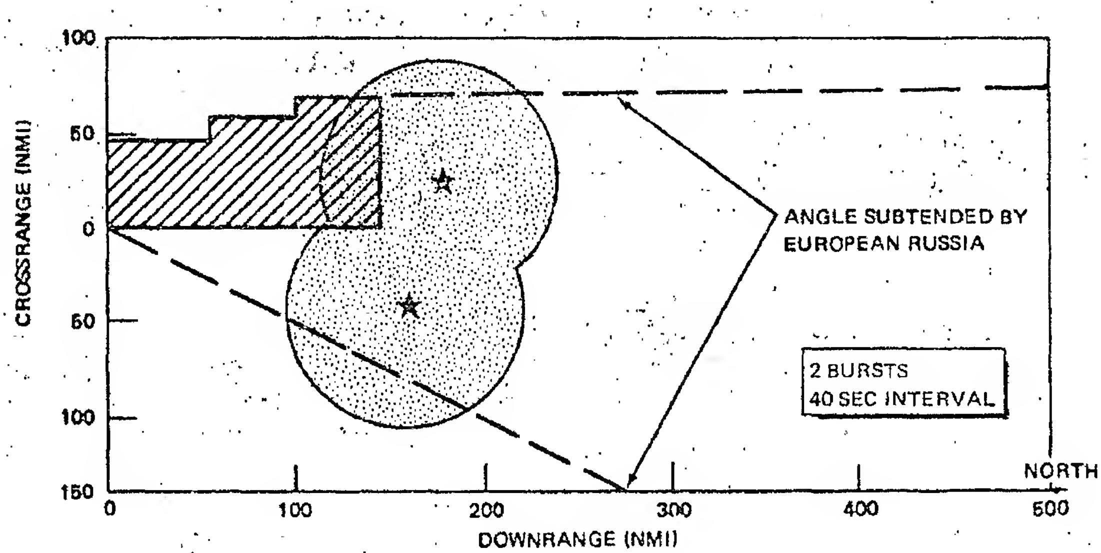


Figure 5-4 Pindown Geometry – Wing VI ; 2 MT Weapon , 1 Cal/Cm^2 (U)

The pindown requirement is extremely sensitive to the attacker's assessment of Minuteman hardness. The number of RV's required varies with the square of the hardness level because a variation in hardness changes both the number required to cover the width of the threat tube and also the time required for Minuteman to fly through the lethal volume. Figure 5-5 shows the requirements for a pindown attack at Wing I if the assessed Minuteman hardness is 5 cal/cm^2 and the SLBM's have 2-Mt warheads. Note that not only are 12 bursts* required to cover the threat tube but also that they must be repeated every 25 seconds.

The overall impact of hardness is shown in Figure 5-6 in terms of the number of RV's required per minute of pindown for both 1- and 2-Mt SLBM warheads.

The duration required for a pindown attack is also subject to some uncertainty arising from the degree of conservatism in the mind of the preemptive planner. Given accurate intelligence (and high confidence in that intelligence), the Soviet planner may realize that Minuteman could not be launched any earlier than 15 minutes after the beginning of the attack. In this case, the pindown duration required is only 15 minutes. In the absence of such intelligence, it seems likely that the planner would elect to make his pindown as secure as possible by beginning at the earliest possible moment and maintaining the attack until his ICBM's reach their targets. In this case, pindown duration is 20 to 22 minutes, depending on the location of the Minuteman wing. In the subsequent discussion, 20 minutes has been used as the pindown duration.

5.4 FLYOUT AGAINST A DEFICIENT PINDOWN ATTACK

The Soviet planner's total inventory requirements for a guaranteed pindown attack can be estimated from Figure 5-6. If the planner is willing to accept some risk and assesses Minuteman hardness at 1 cal/cm^2, and if his SLBM warheads have their estimated yield of 1 Mt, 20 minutes of pindown will require 600 SLBM's on-station within 100 to 200 miles of the U.S. coast. Because it is practical to maintain no more than about two-thirds of an SLBM force on patrol at any one time,** the Soviet planner's requirement for a successful pindown attack under these

*In this case, the depth of the threat tube presents a problem as well as the width so tandem bursts are required (one located approximately 40 nmi above the other) at each of the burst points.

**Actual Soviet ballistic missile submarine operations have not approached this figure. Normally, less than one-fourth of the Soviet missile submarines are at sea and these do not usually patrol within 200 nmi of the U.S. coast (Reference 1).

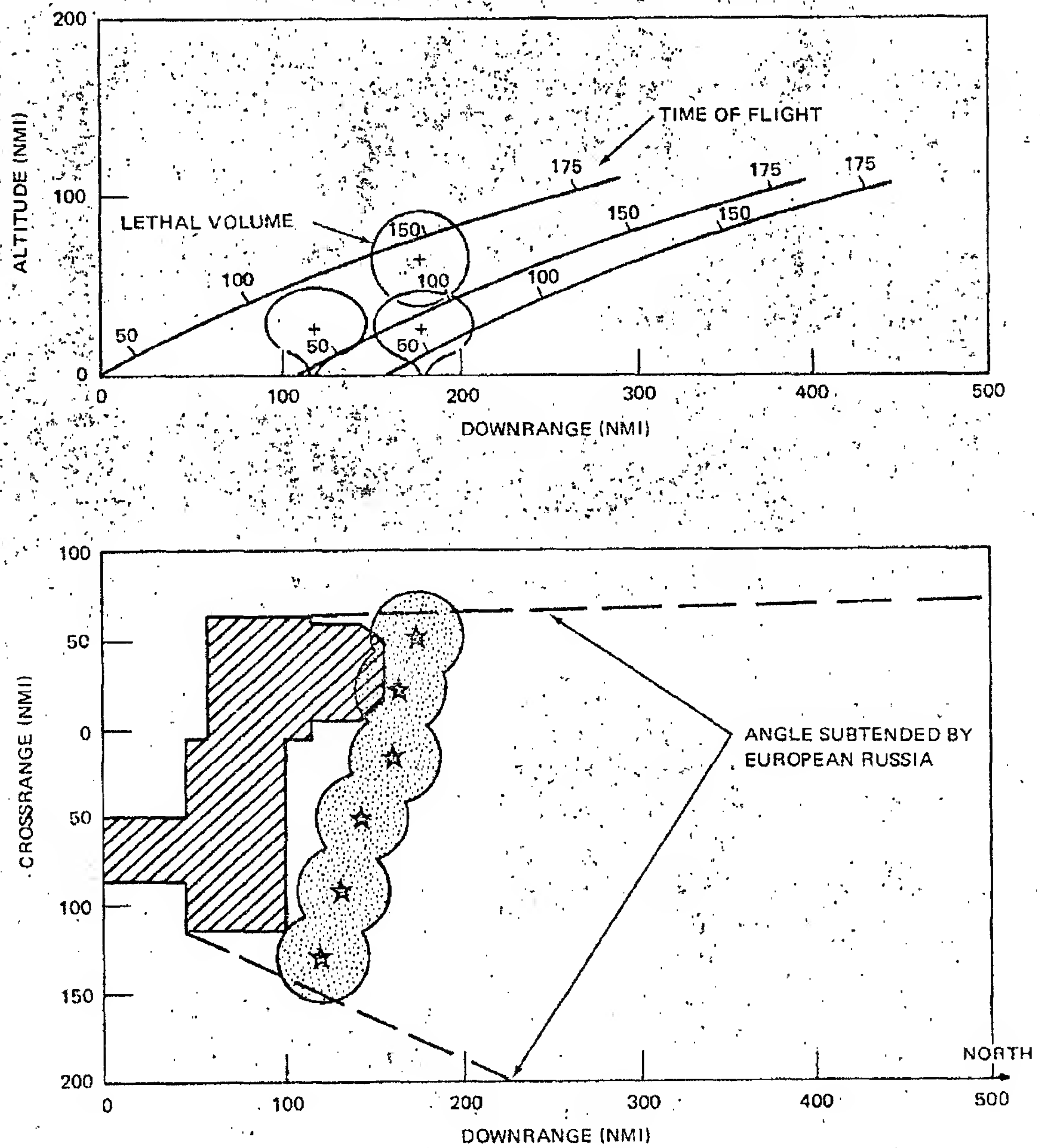


Figure 5-5 Pindown Geometry—Wing I; 1 MT Weapon, 5 Cal/Cm^2 (U)

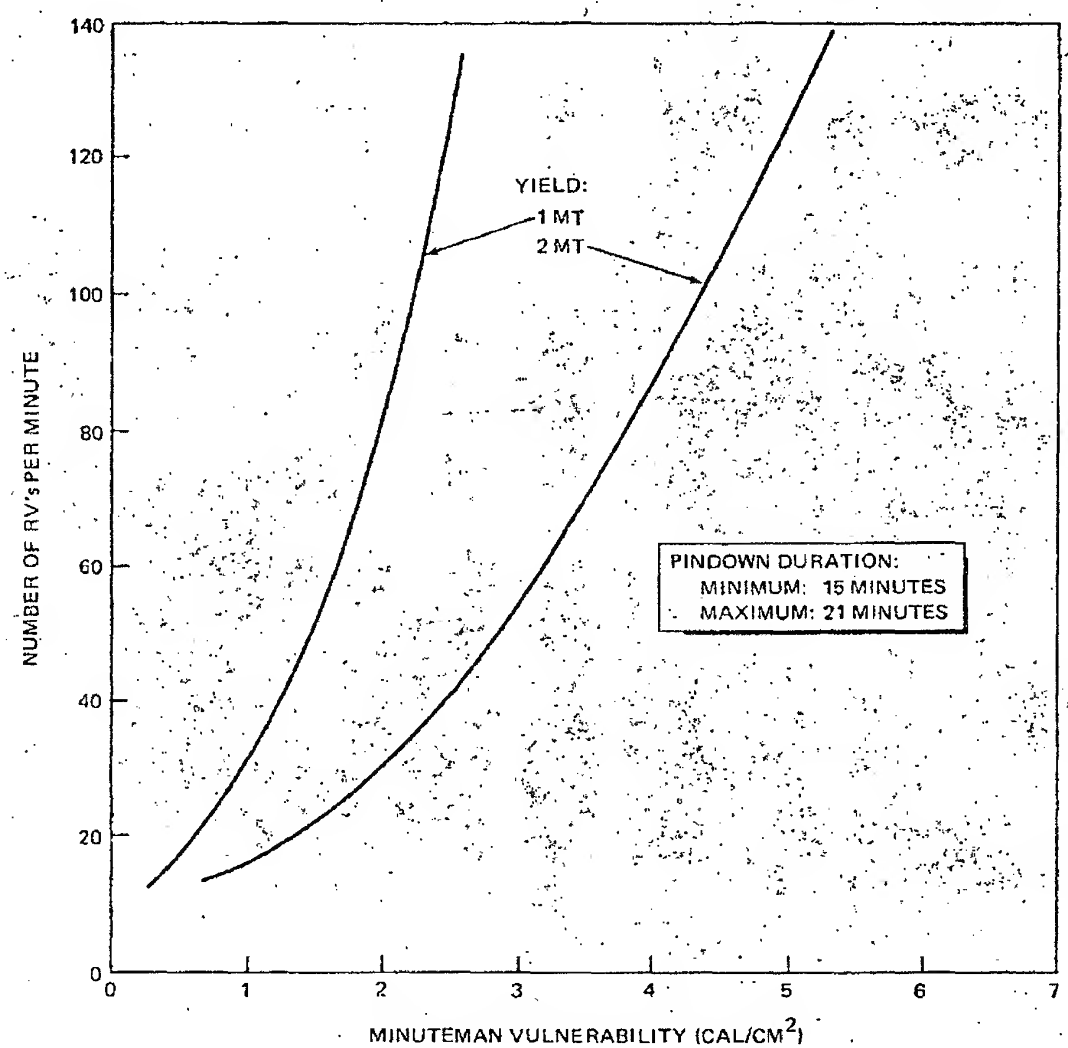


Figure 5-6 Minuteman Pindown Requirements (U)

circumstances is 900 missiles or 56 submarines. At his current rate of production, this level of missiles means he could not mount a guaranteed pindown attack against Minuteman for at least five years.

The possibility that only a few bursts would be required to discourage flyout was raised in Subsection 5.2. If this were the case, then a very small inventory would suffice to keep Minuteman bottled up and the Soviet planner presumably could accomplish the mission at this time. It is the thesis of this section that such an attack would be extremely risky because there is a relatively simple flyout strategy which would guarantee that a significant portion of the Minuteman force would survive the pindown attack. The implementation of this strategy requires no knowledge of the Soviet attack strategy, nor does it require any information about the Soviet forces and their capabilities which cannot be estimated with high confidence based on currently available intelligence.

The strategy discussed below is not one that the U.S. would adopt willingly. It has a number of drawbacks, principal among which is that it would make it very difficult to coordinate the arrival of RV's on multiply-targeted aimpoints. In addition, it requires that the NCA respond without the luxury of a prolonged assessment of the attack (although there would be no doubt as to the reality of the attack and its intent). However, none of these drawbacks are likely to seem sufficient from the Soviet planner's point of view. He must concern himself with what the U.S. <u>can</u> do because he cannot be sure of what we <u>will</u> do. An additional factor in enhancing the credibility of flyout is that the minimum number of survivors is calculable from knowledge of the Soviet inventory alone and is not sensitive to the manner in which it is employed. The actual number of survivors will exceed this level if the Soviet attack is less than optimum.

The flyout strategy is basically very simple: Minuteman launches are timed and sequenced in such a way that no pindown RV can possibly kill more than a fixed number. This tactic is accomplished in the following way: at each wing the duration of the pindown attack is divided by the total number of missiles to be launched; this factor yields the interval between successive launches. Launch sequence is uniformly random over the wing. Consider, for example, Wing I; assume 20 minutes of pindown, a 2-Mt SLBM warhead, and an assessed Minuteman hardness of 1 cal/cm^2. Under these conditions it takes Minuteman at least 50 seconds to transit the lethal volume generated by a single pindown burst. Because the Minutemen are launched 6 seconds apart (20 minutes divided by 200 missiles) 9 missiles at most are potentially vulnerable to the burst of an incoming RV. However, because the launch sequence is distributed uniformly over the entire wing, the likelihood is that no more than three of these will be within one lethal radius of a given burst.

The major result of the flyout tactic is that the number of surviving missiles is sensitive only to the number of attacking RV's. The attacker can do nothing to increase the number of missiles killed by any given RV.

Figure 5-7 shows the effect of this flyout strategy on a deficient inventory pindown attack on Wing I. Here, the expected number of survivors resulting from flyout is plotted as a function of the inventory devoted to pindown at Wing I. The trends are similar at each of the other wings. The data used to generate this figure was provided by a Monte Carlo simulation of the pindown engagement.

Functions like those in Figure 5-7 were generated for each of the Minuteman wings. Each function was approximated linearly using least-squares approximation; then, the resulting linear functions were used as payoff functions to determine an allocation process for a deficient inventory attack across the entire Minuteman deployment. The results are shown in Figure 5-8.

Figure 5-8 plots the number of Minuteman saved by flyout as a function of the SLBM inventory which the Soviets devote to pindown. The secondary abscissa on the figure indicates the number of SSBN's the Soviets would require in order to have the associated pindown capability. The scale on this axis incorporates the following assumptions concerning SSBN availability and utilization:

A. No more than two-thirds of the force is on-station.

B. SLBM availability-reliability is 80%.

C. At least 50 time-sensitive targets will draw SLBM attack; these would include SAC bases and central command installations (Washington, D.C., NORAD Headquarters, etc.).

Figure 5-8 illustrates the folly of a pindown attack with an inventory that is not adequate to guarantee the results. The importance of this figure and the flyout strategy as a whole is not that the U.S. would want to employ such an option, rather, it is that it is wholly credible that the U.S. could employ such an option; any nation planning a preemptive attack on the Minuteman must recognize this credibility and accept the possibility that a preemptive strike against Minuteman may fail completely if not supported by an adequate pindown attack.

As a final point, recall that the requirements shown in Figure 5-8 are minimums and assume a larger-than-estimated SS-N-6 warhead and a Soviet planner banking on U.S. sure-safe levels as adequate for his kill. This weighs the game heavily in favor of the attacker. If, instead, one were to use moderately conservative assumptions (Soviet point of view), the requirements for an adequate pindown attack become

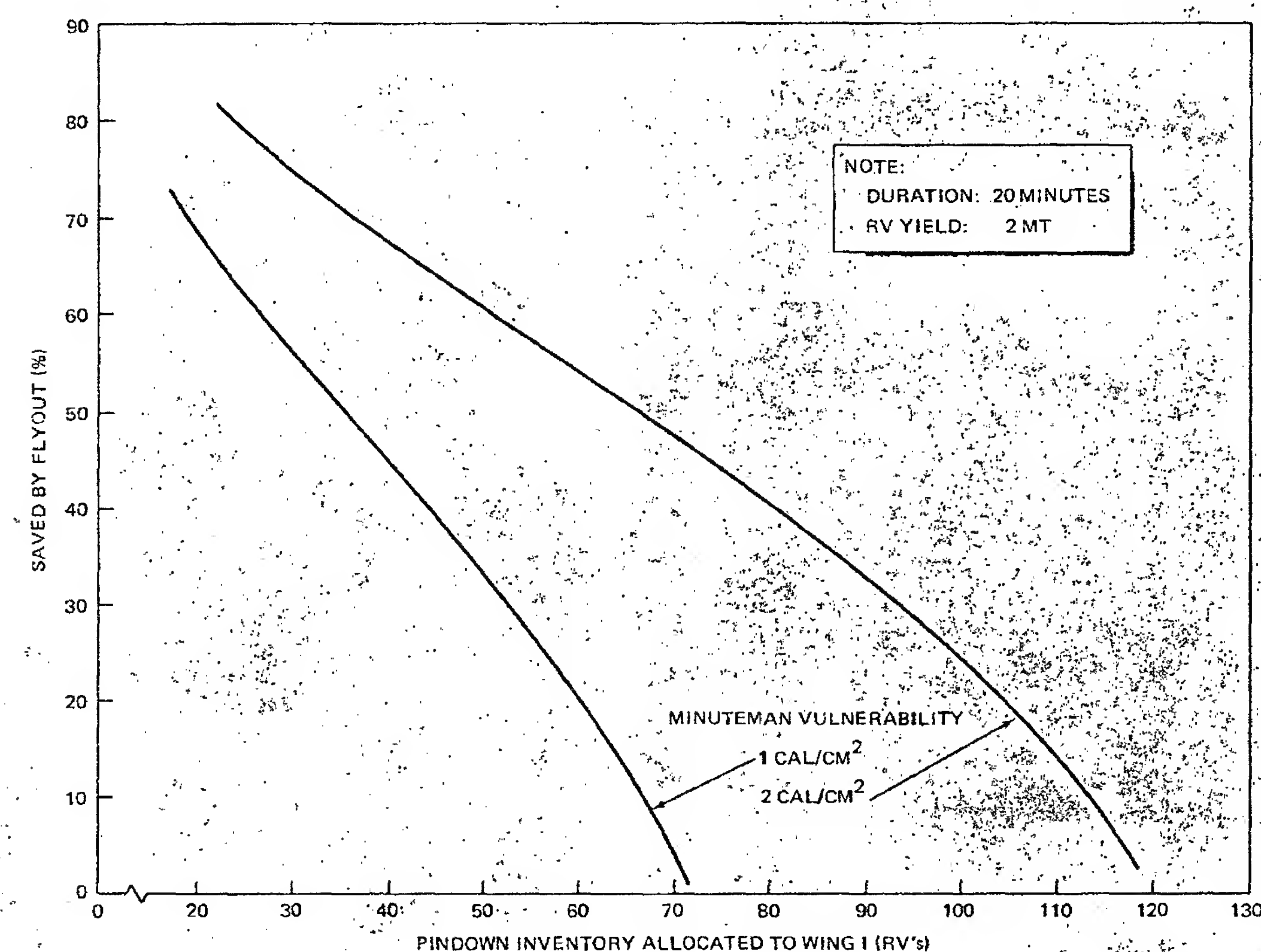


Figure 5-7 Minuteman Saved by Flyout During Attack (Wing I) (U)

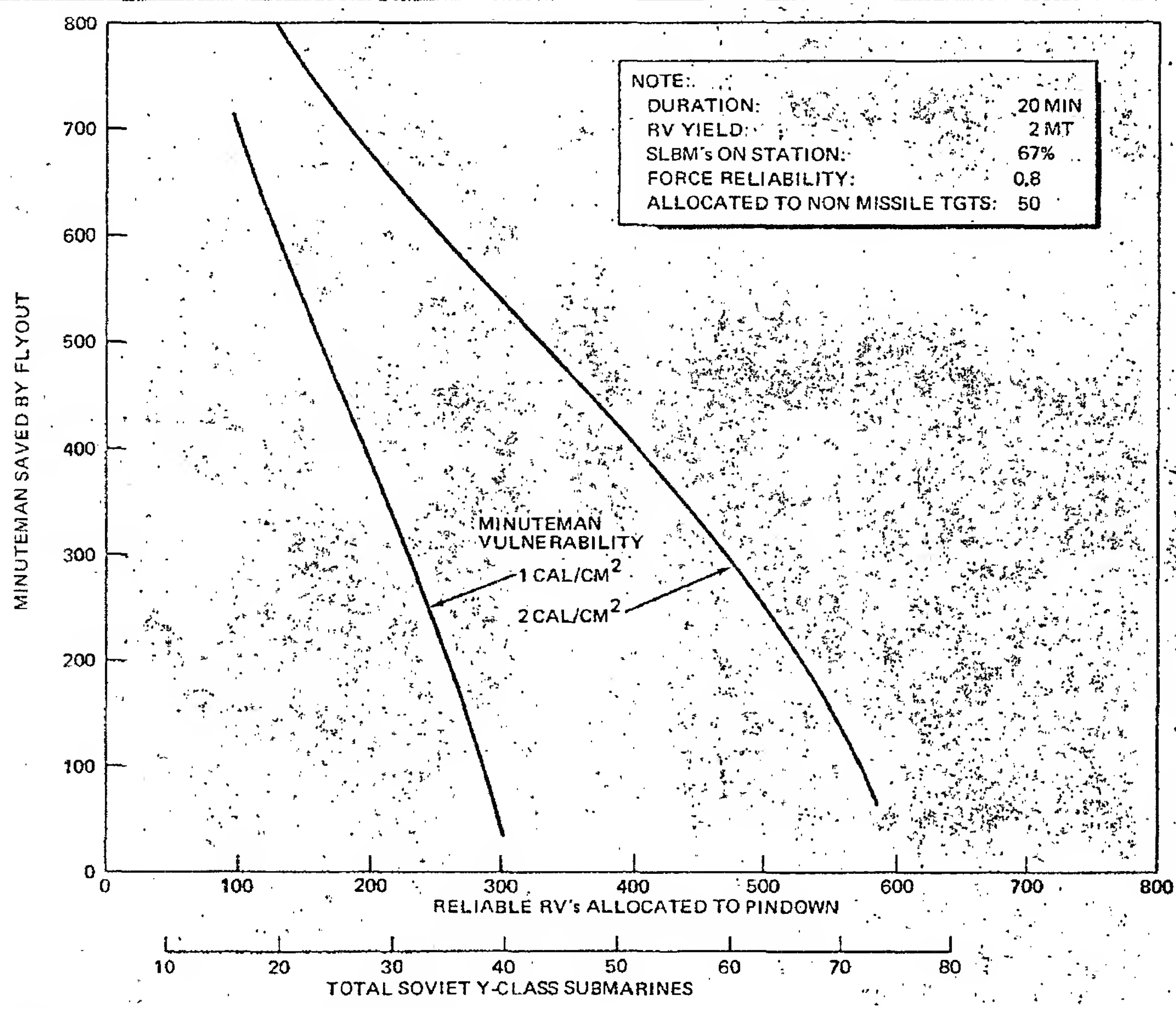


Figure 5-8 Minuteman Saved by Flyout (All Wings) (U)

impractically large. For example, if the Soviets assess Minuteman hardness at 5 cal/cm^2 (which is not impossible or really even improbable), their pindown requirement is approximately 1,900 RV's to insure that no more than 30% of the Minuteman force survives flyout. Factoring in the availability and reliability of the SLBM's generates a requirement for 3,600 RV's or 225 ballistic missile submarines.

If the Soviets were to MIRV their sea-based force it would, if anything, increase the inventory requirement. This rather startling result occurs because of the requirement to cover not only the width of the threat tube but also to cover as long a segment of the Minuteman trajectory as possible. The weight penalty paid in MIRVing generally tends to reduce available yield by at leat 50%; for example, if three RV's were packaged on the SS-N-6, each RV's yield would almost certainly be less than 300 kt. This would give each warhead a lethal radius of at most 22 nmi compared to 58 nmi associated with the single 2-Mt warhead used in the examples (1 cal/cm^2). Thus, the three RV's would give about the same coverage across the threat tube as the single warhead, but the time required for a Minuteman to traverse the lethal volume generated by any of the RV's would be reduced almost by a factor of three. The interval between bursts then must be reduced appropriately which, in turn, drives the inventory requirements up sharply.

5.5 VIABILITY OF PINDOWN

It is never really possible to state with high confidence what the Soviet assessment of a given situation would be, but the numbers which evolve from analyses of pindown requirements are persuasively large and virtually insensitive to qualitative improvements in Soviet systems. It is clear that, whatever his assessment of Minuteman vulnerability, the Soviet planner will require close coordination of a large number of his SSBN's operating very close to U.S. coastlines. The movement of such forces into U.S. coastal waters would in itself be a significant departure from Soviet practice and, thereby, would constitute a potentially provocative act even during a calm period in international relations. During a period of high tension between the U.S. and USSR such an act might be considered a prelude to attack, thereby inviting a first strike by the U.S. At the very least, it would alert the U.S. and undoubtedly flush the manned bomber force.*

In summary, it appears unlikely that the Soviets will have the capability to mount a viable pindown attack within the next few years. If the U.S.

*Until the Soviets deploy missile submarines considerably quieter than their current Y-class SSBN, the U.S. could have high confidence of detecting some indication of such an act.

upgrades the hardness of Minuteman even modestly, Soviet achievement of such capability at any time is unlikely simply because of the sheer numbers of SLBM's that would be required.

Section 6
U.S. OPTIONS

Pindown could be completely discounted as a threat if any one of the following could be accomplished:

A. Hardening of Minuteman guidance and the Minuteman III post-boost propulsion system to 5 cal/cm^2.

B. An enforceable submarine standoff of 500 nmi would be of great value; a 1,000-nmi standoff would be more than adequate.

C. An agreement limiting Soviet SSBN total inventory to some number no more than the U.S. SSBN force (41 boats). This agreement need apply only to Y-class or better submarines.

Hardening of the Minuteman components to 5 cal/cm^2 is not impossible; the guidance set is the most significant problem (the booster is already hard to greater than 5 calories and the Minuteman III post-boost propulsion system could be modified to achieve a comparable level). The Air Force has had a guidance hardening development program under way for three years. The goal of this program is a guidance set for future ICBM applications, but it will also be compatible with the existing Minutemen. Hardness level of this subsystem should be in the 2- to 5-cal/cm^2 region. Operational equipment should be available by the mid-1970's. It is also possible to increase the hardness of the current Minuteman guidance subsystem through shielding but only at the expense of extra weight and, thus, a compromise in range.

Submarine standoff has attractive features as an aid to both Minuteman and manned-bomber survivability. There are major uncertainties in the ability of either nation to verify such an agreement, because of the difficulty of detecting individual submarines on patrol. To support a flyout policy, however, requires only that one of the many submarines which must violate the exclusion zone in order to mount a pindown attack be detected. The probability of such a detection is quite high, e.g., if the probability of detecting a single violation is no more than 0.05, the probability of detecting at least one violator out of the twenty or more that would be required exceeds 0.65. Until Soviet submarines become much quieter the probability of detecting a single violator will remain much greater than 0.05.

An arms control agreement which placed an upper bound on Soviet SLBM deployment is extremely desirable to eliminate the possibility of a pin-down attack. It is not clear at what deployment level the Soviets would agree to such a limit; however, in view of their oft-repeated repudiation of agreements which freeze the situation in an unbalanced position, it seems likely that they would hold out for a force at least equal in numbers to the U.S. fleet ballistic missile force. Should this be the case, a modest improvement in Minuteman hardness (to less than 2 cal/cm^2) would be desirable to maintain an assured flyout capability.

There is one other area in which U.S. action is required before pindown can be discarded as a viable threat. If a flyout strategy is the means for defeating pindown, Minuteman launch planning must contain such an option. It is unlikely that such is the case now because the counterforce threat has yet to materialize. However, within the next few years such an option should be considered. Also, refinement of Minuteman launch control center operations to reduce the time required to execute the launch command is a highly desirable development provided it can be accomplished without compromising fail-safe precautions.

Section 7

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Appendix A

MINUTEMAN PROPULSION AND STRUCTURE VULNERABILITY

A.1 INTRODUCTION AND SUMMARY

The Minuteman ICBM is a retaliatory weapon designed for launch against enemy targets in the event of a first strike against the United States. Its effectiveness as a deterrent and credibility as a weapon is dependent on its ability to fly out of its silo during an attack, survive the effects of pin-down bursts of nuclear weapons, and deliver its payload on target. An important parameter that determines the likelihood that the vehicle will successfully complete its mission is its hardness to the effects of pin-down bursts. This appendix presents the results of a limited study of the vulnerability of the Minuteman II and Minuteman III propulsion systems when exposed to weapon fluences up to 10 cal/cm^2. Overall vehicle system hardness, as it is influenced by systems and subsystems other than propulsion, is considered in Appendix B.

Minuteman uses a three-stage solid propellant booster to accelerate its payload into a ballistic trajectory. A post-boost propulsion system (PBPS) aboard the payload bus provides a final maneuvering capability for weapon delivery. The present vulnerability study examined the propulsion systems for each booster stage, as well as the PBPS, to estimate a "sure-safe" x-ray fluence level for which the probability is high that the propulsion system would not be damaged enough to prevent the vehicle from completing its mission. The three booster stages were found to be inherently hard enough to survive an x-ray fluence of 5 cal/cm^2 over a 1 to 15 kev (blackbody temperature) range of x-ray energy spectra. This result is based on damage criteria that are viewed as "sure-safe"; i.e., they are conservative. Thus, it is possible that a more detailed study would establish a higher inherent hardness level, approaching 10 cal/cm^2, particularly, if test data could be procured to substantiate a less stringent spall criterion for the third-stage fiberglass case.

The PBPS poses a more difficult problem in predicting survivability at fluences exceeding 1 cal/cm^2. A careful and detailed analysis of the Minuteman III PBPS performed by Autonetics Division of North American Rockwell Corporation led to the conclusion that the PBPS would meet the Air Force SAMSO requirement that it be hard to at least 1 cal/cm^2

(Reference A-1). However, the report did not go on to predict the maximum level to which the PBPS might be safe. A later study at MDAC (Reference A-2), performed for the Air Force Rocket Propulsion Laboratory, included a vulnerability assessment of typical rocket engine components which might be used for a liquid propellant PBPS (detailed drawings of the Minuteman III PBPS were not made available for the study, as originally intended). The study showed that most components were hard to x-ray fluences of 5 to 10 cal/cm^2; those not inherently hard to better than 1 cal/cm^2 could readily be protected by a small amount of shielding or minor redesign to increase their hardness to this level. The "sure-safe" analyses performed to date have been conservative, and, consequently, the PBPS is probably actually harder than estimated and can certainly be made harder with relatively little effort. A summary of the results of the MDAC study of PBPS components clearly shows the large range of uncertainty between the relatively certain bounds represented by sure-safe and sure-fail levels. This spread is caused by the difficulty inherent in performing an analysis when there is little test data available for guidance. The sure-safe level is conservatively estimated to be at the point of incipient damage, and, in many cases, is probably well below the level at which failure would actually occur. Thus, it is reasonable to believe the PBPS components could be relatively easily hardened to an x-ray fluence as great as 5 cal/cm^2.

A study is presently underway at MDAC (Reference A-3) on the weight and cost penalties which may be expected in hardening existing rocket propulsion components to fluences as high as 50 cal/cm^2. Information compiled in this study will aid in predicting the cost of hardening the PBPS to a sure-safe level of 5 cal/cm^2. This information will be available around the middle of 1972.

A.2 VULNERABILITY EVALUATION

The major nuclear threat to missiles which operate in the exoatmosphere is from x-rays. This is indicated in Figure A-1 which presents the altitude dependence of the free-field environment for a 4-Mt weapon. The figure shows that at altitudes above 100,000 ft, x-ray effects predominate, while at lower altitudes the x-rays are attenuated by the atmosphere, and neutron and gamma ray effects predominate. Earlier studies (Reference A-4) have shown that propulsion systems are not susceptible at the threat levels of neutrons and gammas which cause failure in other more sensitive missile components such as electronics and warheads. The major threat to propulsion is x-ray induced damage that occurs at altitudes of 100,000 ft or higher. The present evaluation of the booster stages was thus limited to potential x-ray damage at fluences of 5 cal/cm^2 and 10 cal/cm^2 over a 1 to 15 kev range of blackbody energy spectra. Potentially critical areas of damage were noted for each stage, then evaluated on the basis of data presented in a design

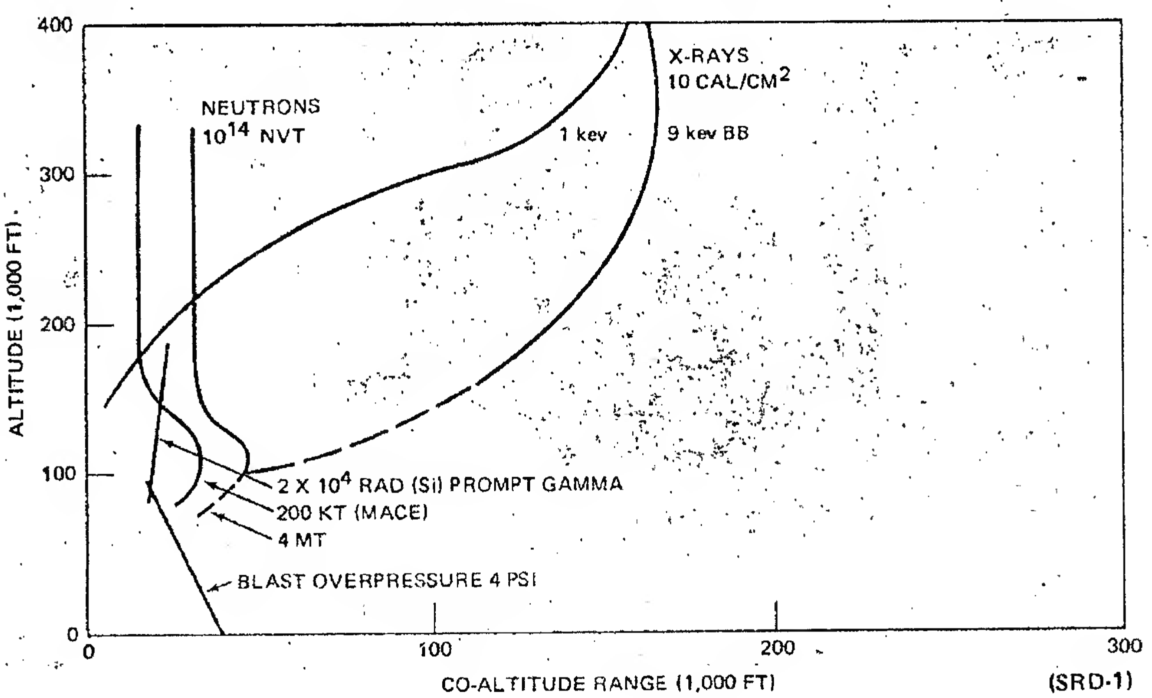

Figure A-1. Altitude Dependence of the Free-Field Environment for a 4-MT Weapon (U)

handbook prepared for the Air Force (Reference A-4) and data prepared as part of a current hardening study being performed for the Air Force (Reference A-3). Potential failure mechanisms were postulated as follows. Previous analyses have shown these mechanisms to be the critical ones that determine propulsion vulnerability at the threat levels considered here.

A. Motor case wall heating due to in-depth energy deposition.

B. Motor case front surface spall due to stress waves.

C. Motor case back surface spall due to stress waves.

D. Case-to-liner bond failure due to stress waves.

E. Liner-to-grain bond failure due to energy deposition in grain.

F. Structural damage to nozzle due to blow-off impulse loading.

G. Nozzle throat insert damage due to up-the-nozzle exposure causing surface damage and debonding.

H. Grain damage due to up-the-nozzle exposure and energy deposition in grain.

The case material and wall thickness for each stage were taken from sheets in the Solid Propellant Information Agency (SPIA) motor manual (Reference A-5) and are tabulated in Table A-1. The data sheets showed that each stage was coated with a thin cork or rubber insulation to limit temperature rise of the case due to aerodynamic heating. For the vulnerability evaluation, it was assumed the insulation was completely charred and ineffective as radiation shielding by the time the second stage ignited at about 100,000 ft altitude. It was also assumed that the thrust vector control components (cold gas valves, piping and tanks) are of a hardness equivalent to that of the propellant valves and cone-spheroid tank evaluated in the MDAC PBPS analysis described in Reference A-2, and are safe to 5 cal/cm^2 or better (unless their electrical controls have soldered joints which are not shielded by enclosures, requiriring a minor fix).

Copies of the x-ray energy deposition curves and induced stress wave curves used for the evaluation have been abstracted from References A-2 and A-4 and are presented in this report. Where data were not available for the precise material used in Minuteman, data for a similar material which will provide similar results have been used. For example, energy deposition curves for A286 steel have been used for the Ladish D6AC of

Table A-1

MINUTEMAN MOTOR CASE DATA (U)

Stage	Wall Material	Wall Thickness	Liner Material	Liner Thickness	Case Insulation	Estimated Insulation Thickness
Minuteman II:						
1	Steel (Ladish D6AC)	0.147 (.373 cm)	Buna N, glass phenolic, carbon phenolic	0.065 (.165 cm)	AVCOAT II	0.070 (.178 cm)
2	Titanium (6A1-4V)	0.104 (.264 cm)	Silica loaded nitrate rubber	0.030 (.076 cm)	AVCOAT II	085 - 0.105 (.216 -.267 cm)
3	S-994 Fiberglass	0.120 (.305 cm)	Silica filled Buna-S	0.030 - 1.410 (076 - 3.58 cm)	RTV-88 & Silica filled buna-Scork	0.10 - 0.370 (.254 -.940 cm)
Minuteman III:						
3	S-994 RTS Fiberglass	0.146 (.371 cm)	SD 851-2	0.025 (0635 cm)	Armstrong 2755 Cork, silica rubber/glass	0.090 (.229 cm)

the first stage, and energy deposition in a PBPS solid propellant has been used to estimate deposition through the case wall into the Minuteman booster grains.

A.2.1 Motor Case Wall Heating

Results of the evaluation are tabulated in Table A-2, and show the wall temperature rise, for all stages, to be within the sure-safe criterion of 50°C for a 5 cal/cm^2 fluence at the worst x-ray energy spectrum between 1 to 15 kev. The temperature rise is that corresponding to the inner motor case surface, and the criterion of 50°C is based on estimated incipient damage to the case/liner bond. This is more critical than case strength loss due to temperature rise. The table also shows how shallow is the depth of material which is melted and removed by surface heating, and thus is not critical in reducing case strength. At 10 cal/cm^2, stages two and three of Minuteman II barely exceed the sure-safe criterion. The temperature estimates used in the analysis are given in the curves of Figures A-2 through A-4. Quasi-equilibrium temperature rise in the motor case wall is read directly from the curve for the appropriate material and thickness. The criterion used for surface melting and material removal is the energy in cal/gm needed to raise the material from room temperature to its melt temperature. It is assumed the melted material is thrown from the surface as the compressive wave generated by in-depth heating is reflected from the front surface of the material. The material removed is 3 mils or less and is not considered enough to cause failure of the wall.

A.2.2 Motor Case Front Surface Spall

Table A-2 also contains the tabulation of response of the motor case wall to front surface spall and back surface spall. It shows all stages to be safe at 5 cal/cm^2 x-ray fluence and the metal cases to be safe at 10 cal/cm^2. The fiberglass cases for the third stage, however, exceed the allowable 1 Kb peak stress criterion at 10 cal/cm^2. The 1 Kb criterion is based on incipient spall of the phenolic binder in the wall and not spall of individual glass fibers. It is thus possible that damage to the wall at 2 Kb may not be deep enough or severe enough to cause the motor case wall to fail, and the case would thus be safe to at least 10 cal/cm^2. Lacking data to prove this to be true, it is prudent to limit the sure-safe fluence to 5 cal/cm^2.

The peak stress values were taken from Figures A-5 through A-7, showing peak stresses calculated with the PUFF hydrodynamics code for steel, titanium and fiberglass. Peak front surface stress was determined by reading the peak tensile stress in the material at the front surface, and then converting the stress reading from the fluence

Table A-2
MOTOR CASE WALL HEATING AND SPALL (U)

Failure Mechanism	Sure-Safe Criterion	Damage at 5 cal/cm² *: Estimated Maximum ΔT (°C)	Damage at 5 cal/cm² *: Estimated Depth Of Material Removed (cm)	(in.)	Damage at 10 cal/cm² *: Estimated Maximum ΔT (°C)	Damage at 10 cal/cm² *: Estimated Depth Of Material Removed (cm)	(in.)
1. Motor Case Wall Heating							
Minuteman II:							
Stage one, Steel (.373 cm)	ΔT = 50°C	< 20	.0006	.00024	< 25	.0012	.00047
Stage two, Titanium (.264 cm)	ΔT = 50°C	< 35	.001	.00039	< 60	.0018	.00071
Stage three, Fiberglass (.305 cm)	ΔT = 50°C	< 35	.003	.00118	< 55	.006	.00236
Minuteman III:							
Stage three Fiberglass (.371 cm)	ΔT = 50°C	< 30	.003	.00118	< 45	.006	.00236

Failure Mechanism	Sure-Safe Criterion	Damage at 5 cal/cm² *: Estimated Peak Stress	Damage at 5 cal/cm² *: Estimated Distance Into Material (cm)	(in.)	Damage at 10 cal/cm² *: Estimated Peak Stress	Damage at 10 cal/cm² *: Estimated Distance Into Material (cm)	(in.)
2A. Motor Case Front Surface Spall							
Minuteman II:	***						
Stage one. Steel (.373 cm)	30 Kb	4.5 Kb at 15 kev	.02	.00787	9 Kb at 15 kev	.02	.00787
Stage two, Titanium (.264 cm)	30 Kb	3 Kb at 5 kev	.01	.00394	6 Kb at 5 kev	.01	.00394
Stage three, Fiberglass (.305 cm)	1 Kb	0.8 Kb at 5 kev	.04	.01574	1.64 Kb at 5 kev	.04	.01574
Minuteman III:							
Stage three Fiberglass (.371 cm)	1 Kb	0.8 Kb at 5 kev	.04	.01574	1.64 Kb at 5 kev	.04	.01574

Failure Mechanism	Sure-Safe Criterion	Damage at 5 cal/cm² *: Estimated Peak Combined Stress at Back Surface	Damage at 10 cal/cm² *: Estimated Peak Combined Stress at Back Surface
2B. Motor Case Back Surface Spall			
Minuteman II:			
Stage one, Steel (.373 cm)	30 Kb	< 4.0 Kb at (15 kev)	< 8.0 Kb at (15 kev)
Stage two, Titanium (.264 cm)	30 Kb	< 4.0 Kb at (5 kev)	< 8.0 Kb at (5 kev)
Stage three, Fiberglass (.305 cm)	1 Kb	1.02 Kb** at (1 kev)	< 2.04 Kb at (1 kev)
Minuteman III:			
Stage three, Fiberglass (.371 cm)	1 Kb	.9 Kb** at (1 kev)	< 1.8 Kb at (1 kev)

*For worst case black body 1 to 15 kev spectrum.
**These values drop to 0.82 and 0.71 Kb, respectively, at a fluence of 4 cal/cm².
***1 Kb = 14,900 psi.

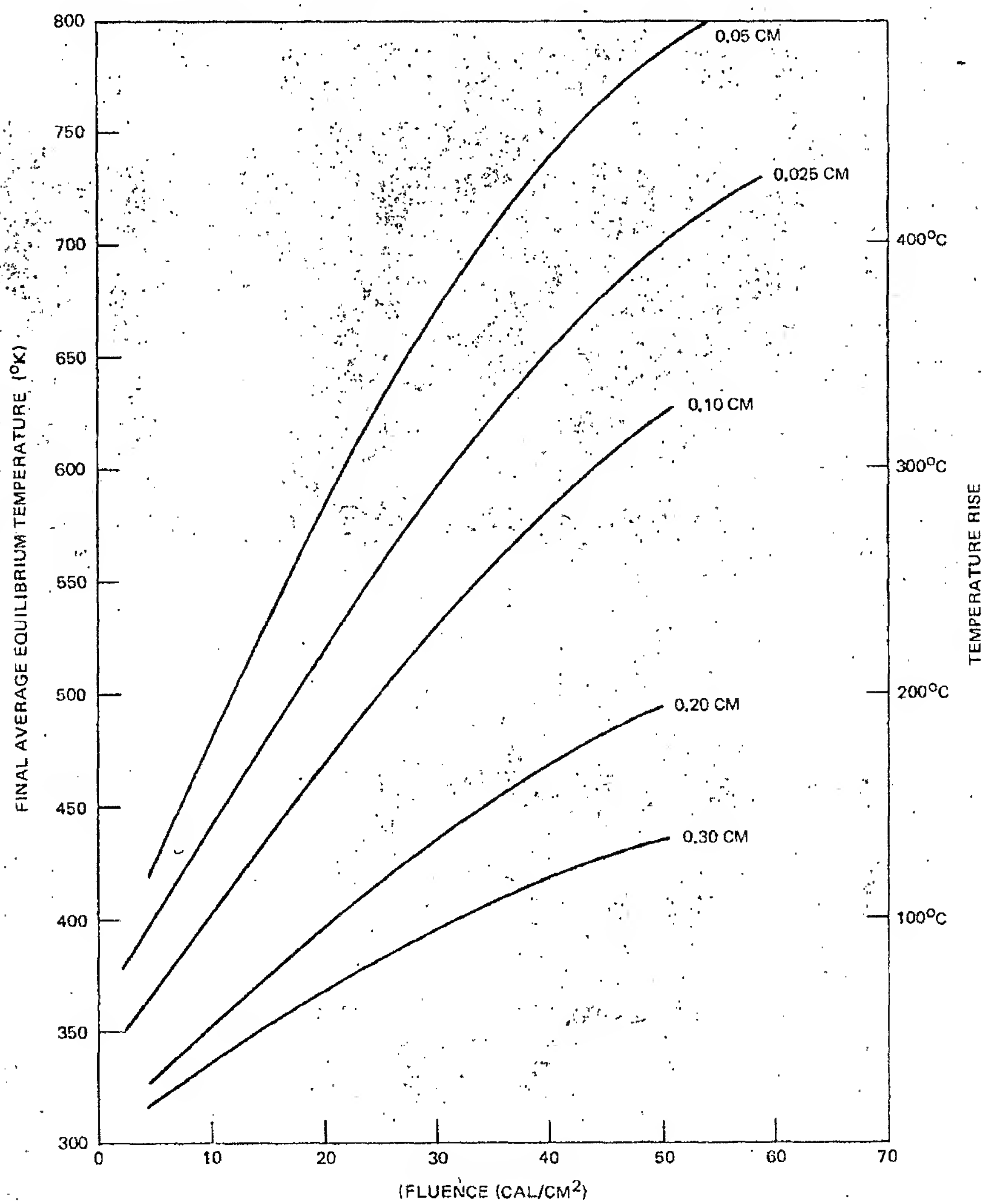

Figure A-2. Temperature Rise for Various Case Thicknesses--Steel

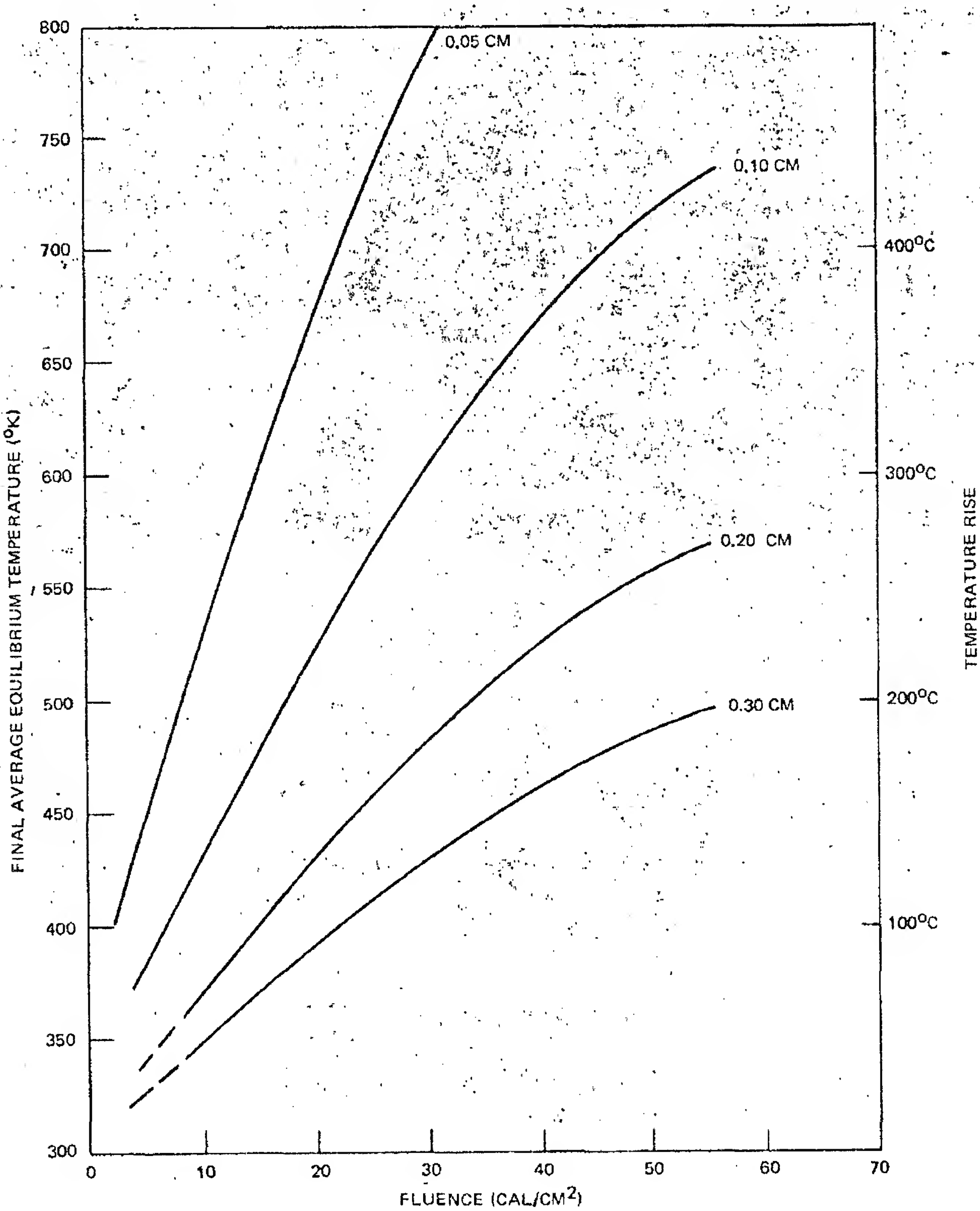

Figure A-3. Temperature Rise for Various Case Thicknesses—Titanium

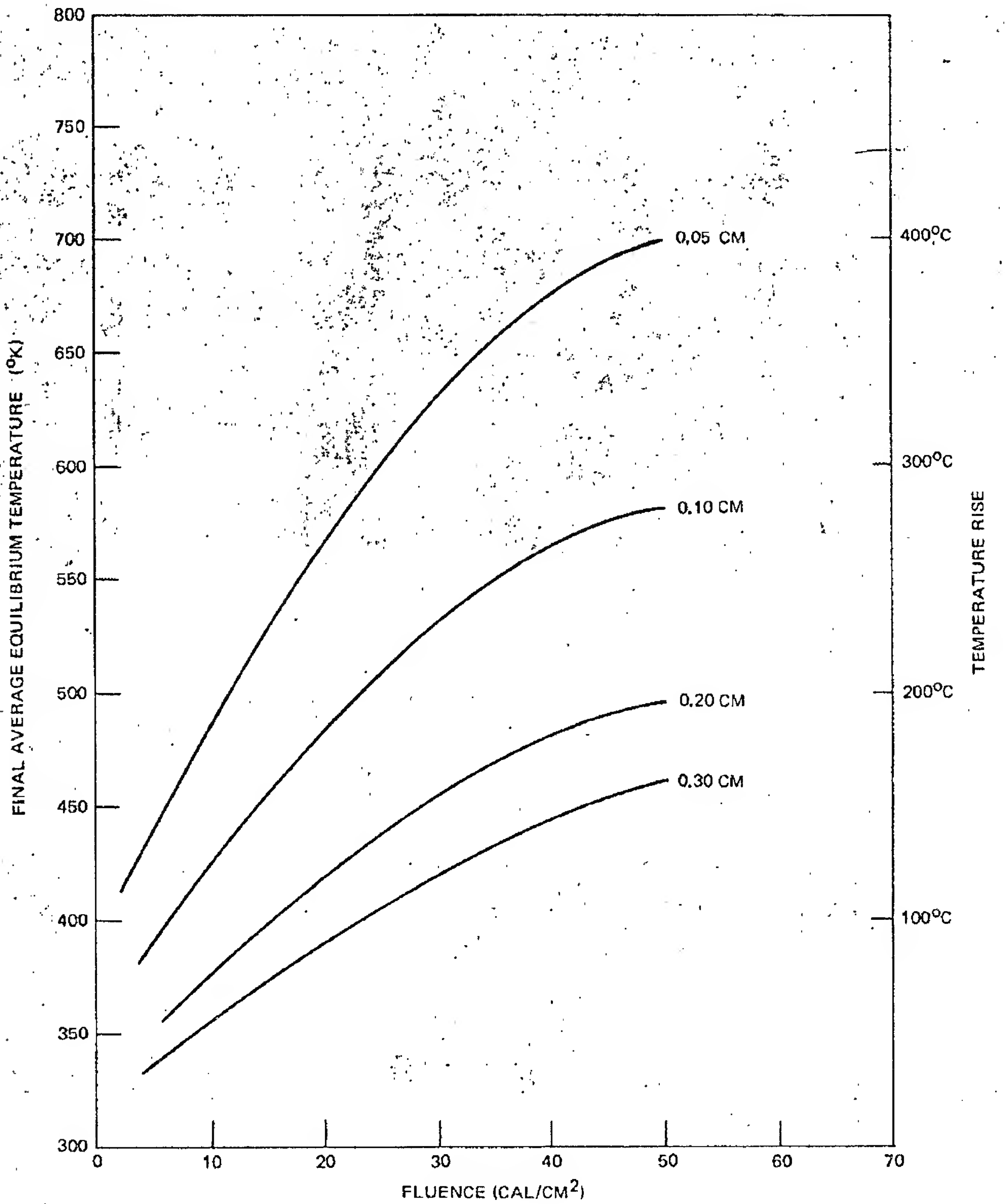

Figure A-4. Temperature Rise for Various Case Thicknesses—Fiber Glass

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noted for the curve to a fluence of 5 cal/cm^2. For example, for A-286 steel (Figure A-5) the stress reading is reduced by the factor .05/100 to convert from 100 cal/cm^2 to 5 cal/cm^2.

A.2.3 Motor Case Back Surface Spall

Back surface spall is also tabulated in Table A-2 and shows the metal cases to be safe to 10 cal/cm^2. The fiberglass case for Minuteman III stage three meets the 1 Kb criterion at 5 cal/cm^2, but stage three of Minuteman II barely exceeds the 1 Kb criterion at 5 cal/cm^2. It does meet the 1 Kb criterion at 4 cal/cm^2 and is safe at that level. In all likelihood the fiberglass case will be safe at 5 cal/cm^2 since the difference between the 1 Kb criterion and the 1.02 Kb estimated stress is well within the tolerance of the accuracy of the predicted stress.

To estimate the back surface peak stress for the metal cases, the compressive and tensile stresses are read off the curves of Figures A-5 and A-6 at the material depth equal to the wall thickness. The compressive and tensile stresses are numerically added to obtain peak reflected stress, then factored by the fluence ratio as was done above for front surface stress. Fiberglass stress is calculated somewhat differently because the peak tensile stress which spalls the wall is a function of the stress which can be reflected from the adjacent liner material. Thus, the peak compressive stress noted from the curves of Figure A-7 must be modified by the ratio of the acoustic impedances (ρC) of the adjacent materials (for metal cases, this factor is insignificant). The expression used is:

$$Pr = \left[\frac{\rho_t C_t - \rho_o C_o}{\rho_t C_t + \rho_o C_o}\right] Po$$

where: Pr = Reflected tensile stress.

Po = Initial compressive stress

ρ_t = Fiberglass density

ρ_o = Liner density

C_t = Acoustic velocity in fiberglass

C_o = Acoustic velocity in liner

For the present calculation, the following values for the fiberglass wall and liner were taken from Reference A-4 and used as representative values.

	ρ	ρC
Silocon rubber liner	1.42	1.38×10^5
GE Phenolic fiberglass	1.91	6.36×10^5

Thus,

$$Pr = \left(\frac{6.36 - 1.38}{6.36 + 1.38}\right) Po$$

where

Po = 1.6 Kb for Minuteman II stage three (.30 cm wall)

Po = 1.4 Kb for Minuteman III stage three (.37 cm wall)

and the reflected tensile stress is

Minuteman II	Minuteman III
$Pr = \frac{4.98}{7.74} (1.6) = 1.024$ Kb	$Pr = \frac{4.98}{7.74} (1.4) = 0.896$ Kb

Thus, both Minuteman II and Minuteman III meet the sure-safe criterion, for a fluence of 5 cal/cm^2, for not causing back surface spall of the motor cases.

A.2.4 Case to Liner Bond Failure

Failure of the case to liner bond due to stress waves can lead to failure of the case from overheating by burning propellant. Scaling data presented in Table XXVII of Reference A-2 to the fluences of interest, the peak tensile stresses in the bond were estimated. All stages, as shown in Table A-3, were found to be safe to at least 10 cal/cm^2. These results are considered reasonable on the basis of tests of similar bonded specimens (Reference A-6) which showed the following:

Material	Case to Liner Bond Failure Level	Material Thickness
Steel	6.7 cal/cm^2 at 8 kev	.63 cm
Titanium	7.9 cal/cm^2 at 8 kev	.28 cm
Fiberglass	No Damage	.35 cm
Fiberglass	No Damage	.74 cm

Table A-3

CASE TO LINER BOND (U)

Critical Areas	Sure-Safe Criterion	Damage at 5 cal/cm² Estimated Peak Stress Tensile (Kb)	Damage at 5 cal/cm² Material Thickness (cm)	Damage at 10 cal/cm² Estimated Peak Stress Tensile (Kb)	Damage at 10 cal/cm² Material Thickness (cm)
Case To Liner Bond Failure					
Minuteman II:					
Stage one Steel (.373 cm)	1 Kb	.09 (15 kev)	.20	.17 (15 kev)	.20
Stage two Titanium (.264 cm)	1 Kb	.09 (15 kev)	.135	.17 (15 kev)	.135
Stage three Fiberglass (.305 cm)	1 Kb	.23 (1 kev)	.20	.45 (1 kev)	.20
Minuteman III:					
Stage three Fiberglass (.371 cm)	1 Kb	.23 (1 kev)	.20	.45 (1 kev)	.20

From these tests it would appear evident that the case to liner bond is safe to better than 5 cal/cm^2. It is possible the bond is good to levels exceeding the 7 and 8 cal/cm^2 shown, since there is evidence that the bonds tested did not develop their full strength potential.

A.2.5 Liner to Grain Bond Failure

Evaluation of the liner to grain bond shows the dose to be less than the damage criterion of 10^6 rads, at 10 cal/cm^2, for all stages of the missile. The values shown in Table A-4 were developed from the x-ray energy deposition curves of Figures A-8 through A-10. Using these curves, the dose to be expected in a typical motor grain shielded by various motor case materials and thicknesses is shown in the figures. The dose in cal/gm per cal/cm^2 is read directly from the curves and then multiplied by 4.2×10^5 rads per cal/gm to convert the dose to rads. The results are tabulated in Table A-4.

A.2.6 Structural Damage to Nozzle

A possible source of damage to all stages of the Minuteman booster is structural damage caused by excessive deflection of the motor case or nozzle structure due to blowoff impulse. The current MDAC study of propulsion hardening techniques (Reference A-3) has determined that the integrated structure of case, liner and grain for thin wall motor cases is resistant to structural damage at fluence levels in excess of 20 cal/cm^2. Therefore, this analysis was limited to evaluation of the nozzle exit cones. The exit cones of the exhaust nozzles of all three stages are unshielded by surrounding structure, particularly in the event of illumination from the rear. The assumption was made that the exit cone materials were silica phenolic composite materials. They were analyzed using the single-zone approximation given by Equation 3-3 of Reference A-4. This showed, as tabulated in Table A-5, that the exit cone impulse is well below the sure-safe criterion of 1,000 taps (1 tap = 1 dyne-sec/cm^2) at a fluence of 10 cal/cm^2.

Calculation of the estimated impulse the exit cones will experience is as follows. From basic material data, the density and sublimation energy for silica cloth phenolic are obtained. From the deposition curves of Figure A-11, energy deposited and the depth of the affected zone are obtained for 1 kev, the worst case for producing blowoff impulse. Thus, the blowoff impulse, in taps, is given by

$$I_B = 9,150 \sqrt{\rho \Delta X} \left[\sqrt{H - E_s \ \rho \Delta X} \right]$$

Table A-4

GRAIN TO LINER BOND (U)

Critical Areas	Sure-Safe Criterion	Deposition Through The Case Wall Into The Grain	
		Dose at 10 cal/cm^2 (Rads)	Dose at 5 cal/cm^2 (Rads)
Debond of Grain to Liner Bond Due to Grain Failure			
Minuteman II:			
Stage one Steel (.373 cm)	10^6 Rad* in Grain	3.15×10^4	1.53×10^4
Stage two Titanium ((.264 cm)	10^6 Rad in Grain	1.18×10^5	5.9×10^4
Stage three Fiberglass (.305 cm)	10^6 Rad in Grain	3.15×10^5	1.58×10^5
Minuteman III:			
Stage three Fiberglass (.371 cm)	10^6 Rad in Grain	3.02×10^5	1.51×10^5

*1 cal/gm = 4.2×10^5 rads

Figure A-8. Energy Deposition in PBPS Propellant Surface Under Steel and 2.54 cm Liner (U)

Figure A-9. Energy Deposition in PBPS Propellant Surface Under Fiber Glass and 2.54 cm Liner (U)

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Table A-5

NOZZLE STRUCTURAL DAMAGE (U)

Critical Area		Sure-Safe Criterion	Calculated Impulse	
			at 5 cal/cm^2	at 10 cal/cm^2
Structural Damage to Nozzle				
Minuteman II:				
Stage one	Silica Phenolic Exit Cone	1,000 Taps	251 Taps	964 Taps
Stage two				
Stage three				
Minuteman III:				
Stage three				

Figure A-11. Energy Deposition in Silica Phenolic (MX-2600) (U)

where

ρ = Material density (gm/cm^3)

E_s = Energy to sublimation for the material (cal/gm)

ΔX = Thickness of affected zone (cm)

H = Total energy deposited in zone (cal/gm)

For silica cloth phenolic, $\rho = 1.26\ gm/cm^3$ and $E_s = 738$ cal/gm.

From Figure A-11 the following values are obtained:

$5\ cal/cm^2$	$10\ cal/cm^2$
$\Delta X = .00073$ cm	$\Delta X = .0016$ cm
$H = 1.5\ cal/cm^2$	$H = 7\ cal/cm^2$

The X values are taken from the intercept of the 1 kev dose curve (solid line) with the dose at 147.6 cal/gm per cal/cm^2 for $5\ cal/cm^2$ fluence and 73.8 cal/gm per cal/cm^2 for $10\ cal/cm^2$ fluence. The same intercept point, the thickness intercept with the dashed 1 kev line, then provides the energy summation for each fluence. Fluence multiplied by the energy summation value gives the above values for H. The formula can now be solved.

at $5\ cal/cm^2$

$$I_B = 9,150\sqrt{1.26\,(.00073)}\left[\sqrt{1.5 - 738\,(1.26)\,(.00073)}\right] = 251 \text{ taps}$$

at $10\ cal/cm^2$

$$I_B = 9,150\sqrt{1.26\,(.0016)}\left[\sqrt{7.0 - 738\,(1.26)\,).0016)}\right] = 964 \text{ taps}$$

Since the calculated impulse is less than the 1,000 taps criterion, the nozzle is estimated sure-safe to $10\ cal/cm^2$ fluence.

A.2.7 Nozzle Throat Insert Damage

It is estimated that the nozzle throat insert can survive an x-ray fluence of $5\ cal/cm^2$. All the nozzles of the three stages of the booster

are fabricated with tungsten throat inserts. Tungsten is a high atomic number material which readily absorbs incident x-ray energy. It is, therefore, generally considered a sensitive material to choose for use in a vehicle which will be exposed to the effects of a nuclear weapon.

An analysis of a rocket nozzle with a tungsten throat performed as part of a study for the Army Materials and Mechanics Research Center (Reference A-7) showed the sure-safe level of the tungsten to be less than 5 cal/cm^2. The analysis was based on hot tungsten (i. e., the motor was operating when exposed) and an exhaust gas area density of 7×10^{-2} gm/cm^2 which shields the nozzle throat from low energy x-rays. The damage mechanisms investigated were insert surface damage and debonding of the insert from the nozzle due to stress waves.

A nozzle of the same design, exposed to high energy (9 to 20 kev) x-rays in an underground test at a fluence of 23 cal/cm^2, showed only very slight surface pitting and no sign of damage sufficient to cause the insert to fail. The nozzle was tested when the material was cold, and it had no protective shielding by combustion gases.

The shielding that a nozzle throat insert receives from the combustion gases is a function of the gas density, but more importantly the distance the x-rays must travel through the gas before reaching the throat. This is a function of nozzle size, and the Minuteman nozzles are longer (by a factor of 3 to 4) than the nozzle which was analyzed. Since the nozzle in the underground test survived an actual exposure at 23 cal/cm^2 of high energy x-ray, and since the combustion gases in the Minuteman nozzles would act to screen out low energy x-rays and leave only the high energy threat, it is reasonable to assume that the Minuteman throat insert would survive a fluence of 5 cal/cm^2; less than one-fourth the fluence to which the test nozzle was exposed.

A.2.8 Grain Damage - Up-the-Nozzle Exposure

In the event of an up-the-nozzle exposure for stages two and three of Minuteman, it is possible for x-rays to shine through the nozzle throat and illuminate the surface of the grain. With the motor operating, some shielding is provided by the combustion gases passing through the nozzle. An estimate of the dose which could be deposited in the grain was made by developing the curve shown in Figure A-12 from deposition data presented in Figure A-17 of Reference A-2. The curve shows the estimated dose as a function of exhaust gas shielding, and represents the maximum dose for x-ray spectra between 1 to 15 kev. The sure-safe dose level for a typical grain is taken to be 5×10^6 rads. This dose is not exceeded at a fluence of 5 cal/cm^2 if the path through the

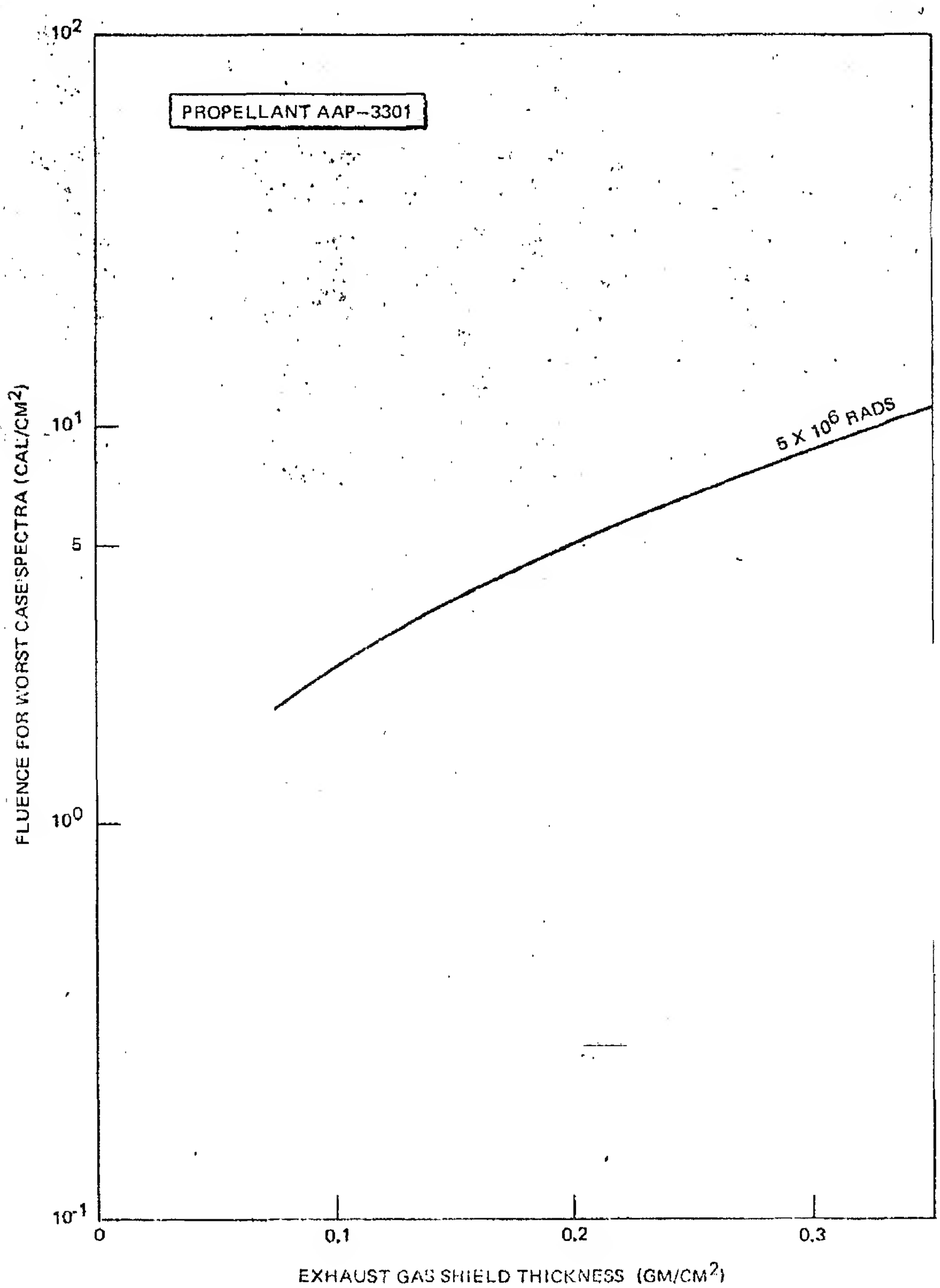

Figure A-12. Damage Threshold for Up-Nozzle Exposure of Solid Propellant

exhaust gas is long enough to provide 0.2 gm/cm^2 shielding. In the analysis of Reference A-7, the gas thickness was calculated to be .07 gm/cm^2 for a small, short nozzle. The stage two and stage three Minuteman nozzles are sufficiently longer to provide a multiplication factor of 3 or greater, and, therefore, satisfies the 0.2 gm/cm^2 necessary to be safe at 5 cal/cm^2.

A.2.9 Post-Boost Propulsion System (PBPS) Vulnerability

Detailed analysis of the Minuteman III post-boost propulsion system to determine the sure-safe fluence level of the PBPS requires more information and time than was available for this evaluation. At this time the best estimate of PBPS hardness is that it is safe to at least 1 cal/cm^2. This was the conclusion of the Autonetics study (Reference A-1) performed for SAMSO. However, the study did not go on to estimate a maximum sure-safe level for the PBPS, and to do so would require detail design information which is not readily available. Consequently, the most that can be said is that the PBPS is safe to 1 cal/cm^2 but is probably safe to, or can easily be hardened to, a higher level approaching 5 cal/cm^2. This estimate is based on the study of typical PBPS components MDAC performed for AFRPL (Reference A-2) and the results shown in Table A-6.

The MDAC study showed that most components were hard to better than 1 cal/cm^2, and where components were extremely soft they could readily be hardened through simple redesign or replacement of vulnerable materials with harder materials. For example, replace teflon bonding with a different bond material, or use welded instead of soldered connections for electrical systems. The study also revealed a very large unknown area between the fluence levels at which incipient damage occurred and the fluence levels which clearly rendered a component inoperative. When incipient damage is estimated to occur at a very low fluence level, it is probable that the component could withstand more than just incipient damage without failure. This would have the effect of narrowing the gap between sure-safe and sure-fail and increasing the sure-safe fluence level. For this reason the PBPS is estimated to be harder than 1 cal/cm^2 and readily shielded or modified to harden it to 5 cal/cm^2.

A.2.10 Summary

In summary, the propulsion systems of the three stages of Minuteman II and Minuteman III are safe to 5 cal/cm^2 at the worst black body temperature between 1 and 15 kev. Small components such as those in the thrust vector control systems or reverse thrust motors are probably inherently hard or are small enough to be shielded to 5 cal/cm^2 at minimum penalty. Finally, the PBPS is safe to at least 1 cal/cm^2 but is probably hard to 5 cal/cm^2 or more.

Table A-6 (page 1 of 2)

L-6 PBPS SURVIVABILITY AND HARDENING SUMMARY (U)

Component	Survive	Failure Mode			Failure Criteria		Damage Thresholds				Hardening Recommendations
							Sure-Safe		Sure-Kill		
		Part	Mode	Radiation	Sure-Safe	Sure-Kill	Fluence (cal/cm^2)	X-ray BB (keV)	Fluence (cal/cm^2)	X-ray BB (keV)	
N_2O_4 Positive expulsion tank	No	Tank/ teflon bond	Debond	X-ray	Incipient debond (10^{-2} kbT)	Spall of tank back surface (49 kbT)	2 <1	1 5-15	>200	1-15	Teflon liner requirement limits survivability. Other methods of preventing diaphragm slippage should be employed, or eliminate need for bond.
Explosive actuation valve	No	Explosive lead azide	Detona-tion	X-ray	5 cal/gm	15 cal/gm UGT data	2.3	15	5	15	Add thermal shield to explosive lead azide; also shock-isolate or replace lead azide by organic explosive.
Cone spheroid propellant tank	Yes		None								None
Monopropel-lant engine (75-lb thrust)	No	Retainer screen	Melt	X-ray	Incipient melt ($\Delta X=10^{-4}$ cm) ($\Delta T=420°C$)	Complete melt ($\Delta X=1.1 \times 10^{-2}$ cm) ($\Delta T=420°C$)	<1 2 10	1-5 9 15	>100 37 23 26	1 5 9 15	Modify lower support plate design to slant perforations and thereby shield retainer screen and catalyst.
	No	Shell 405 catalyst	Melt	X-ray	Incipient melt of iridium ($\Delta T=1470°C$)	Substantial melt ($\Delta X=2.5 \times 10^{-3}$ cm) ($\Delta T=1470°C$)	<0.1 0.3 0.8 20	1 5 9 15	~1000 24 12 11	1 5 9 15	
			Fracture	X-ray	Fracture of iridium (7 cal/gm)	Severe fracture (70 cal/gm)	2	15	20	15	
	No	Heat shield	Melt	X-ray	Melt 10% ($\Delta T=400°C$)	Complete melting ($\Delta T=400°C$)	0.4 1 3 8	1 5 9 15	>500 25 70 >150	1 5 9 15	Increase heat shield thickness to prevent total melting. Reinforce heat shield against impulsive loading.
			Impulsive load	X-ray	Impulsive load-ing (130 taps)	Impulsive loading (1000 taps)	4 6	0.5 1	300	0.5-1.0	
Fuel Valve	No	Solder joint	Spall	X-ray	Incipient spall (4.6 cal/gm)	Complete spall (46 cal/gm)	2.5	15	25	15	Eliminate high "Z" solder, or shield solder by increasing cover thickness.
Bipropellant valve	No	Pintle and seat	Heating	X-ray	Heating to 100°C ($\Delta X=10^{-5}$ cm) through 0.15 cm 304SS	Heating to 500°C ($\Delta X=10^{-5}$ cm)	>100 80 6 2	1 5 9 15	>400 30 10	1-5 9 15	Replace WC (Kenametal) Poppets and seats with adequate lower Z material.

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Table A-6 (page 2 of 2)

Component	Survive	Failure Mode: Part	Failure Mode: Mode	Failure Mode: Radiation	Failure Criteria: Sure-Safe	Failure Criteria: Sure-Kill	Damage Thresholds, Sure-Safe: Fluence (cal/cm^2)	Damage Thresholds, Sure-Safe: X-ray BB (keV)	Damage Thresholds, Sure-Kill: Fluence (cal/cm^2)	Damage Thresholds, Sure-Kill: X-ray BB (keV)	Hardening Recommendations
Bipropellant valve (Cont)	No	Solder joint	Melt	X-ray	Incipient melt ($\Delta X=10^{-5}$ cm)	Complete melt ($\Delta X=10^{-2}$ cm)	7	9.5	35	9.5	Same as Fuel Valve
			Spall	X-ray	Incipient spall (Q=4.6 cal/gm)	Severe spall (Q=46 cal/gm)	<1	9.5	5	9.5	
	No	Coil assembly magnet	Surface vaporization	X-ray	Heating of magnet to 200°C ($\Delta X=10^{-5}$ cm)	Surface vaporization ($\Delta X=10^{-5}$ cm) (Q=2075 cal/gm)	5	6.6	>100	1-15	Increase thickness of motor cover.
	No	Coil copper wire	Melt	X-ray	Heating to 100°C ($\Delta X=10^{-5}$ cm)	Incipient melt ($\Delta X=10^{-5}$ cm)	5	5.8	25	5.8	Use wire insulation with higher temperature capability, or increase thickness of motor cover.
3000-lb thrust bipropellant engine	No	Case Insulation	Debond from case	X-ray	Incipient debonding (0.1 kbT)	Debonding (1 kbT)	13 9 30	1 5-9 15	130 90 300	1 5-9 15	No hardening advanced.
	No	Injector	Melt	X-ray	Melt of 10^{-3} cm thickness ($\Delta T=850°C$)	Melt of 10^{-2} cm thickness ($\Delta T=850°C$)	7 5 11 29	1 5 9 15	>100 60 75 88	1 5 9 15	With the possible exception of the Fiberite insulation, the propellant engine can probably survive 10 cal/cm^2 of X-rays. None of the materials are particularly sensitive to radiation degradation. Elimination of requirement for insulating the injector would eliminate heating problem if Fiberite insulation is debonded.
	No	Fiberite insulation	Melt	X-ray	Melt of 10% thickness ($\Delta X=0.05$ cm) ($\Delta T=520°C$)	Melt of 30% thickness ($\Delta X=0.15$ cm) ($\Delta T=520°C$)	5.6 .21 55 188	1 5 9 15	23 33 90 228	1 5 9 15	
	No	Injector Insulation Fiberite	Debond	X-ray	Injector surface temperature to 500°C ($\Delta T=340°C$) ($\Delta X=10^{-5}$ cm)	Surface temperature at melt (T=340°C) (Q=250 cal/gm)	35 2.2 4.1 8.8	1 5 9 15	250 15.6 21.3 63	1 5 9 15	
Pressurization system	Yes	Teflon boot	Radiation damage	X-ray	10^6 rad	10^7 rad	>200 14 4	1-5 9 15	>400	1-15	None, sure-safe criterion is probably very conservative

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A.3 REFERENCES

A-1 Final CDR Report on Post-Boost Propulsion System Hardness (U). Autonetics Division of North American Rockwell, Report No. C8-529/601, April 1968. (S/RD)

A-2 Nuclear Weapons Effects on Propulsion Systems, Volume III, Survivability of Post-Boost Propulsion Systems (U). McDonnell Douglas Report No. DAC-63144, May 1969. (S/RD)

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APPENDIX B

MINUTEMAN GUIDANCE AND CONTROL VULNERABILITY

This appendix deals with the vulnerability of the Minuteman guidance and control (G&C) system during launch. The lethal mechanisms are described along with their impact on the critical elements of the Minuteman G&C subsystem. Also, the design hardness criteria for Minuteman III are presented. Directions for further hardening are discussed briefly but no attempt has been made to estimate the ultimate hardness of the system. This appendix relies heavily on Reference B-1 for Minuteman vulnerability data.

B.1 NUCLEAR WEAPON LETHAL MECHANISMS

There are five basic categories of lethal emissions from a nuclear detonation--gamma radiation, neutrons, thermal radiation, electromagnetic radiation, and debris. These affect the Minuteman system in two basic ways--by the rate at which they impinge upon the system or by the total dose absorbed by the system. The effects of neutrons, in particular, result from total dose absorbed rather than the rate, but the effects of gamma rays and thermal radiation (which is almost entirely in the form of x-radiation in the exoatmospheric region) result primarily from the dose rate.

The nuclear environments that the Minuteman launch vehicle must withstand (design criteria) are shown in Table B-1 taken from Reference B-2. Survival in these environments is defined to mean that exposure at these levels shall not result in a system CEP degradation of more than 425 ft (based on a 90-day calibration cycle). The criteria specified in Table B-1 are considered the most critical. Such effects as air blast, thermal radiation (at wave lengths below x-radiation), beta particles, gamma dose, and debris are not important in comparison to those listed. Technical terms used in Table B-1 are defined in the glossary at the end of this appendix.

B.2 WEAPON EFFECTS ON MINUTEMAN G&C COMPONENTS

Each of the nuclear weapon environments affects the system in a different way and different elements of the system are most sensitive to each effect. However, the electronics are definitely the most

Table B-1

ASCENT PHASE NUCLEAR ENVIRONMENT (U)

Environment	BSD 63-67B Paragraph	Criterion
Prompt Gamma and Penetrating X-Rays	5.1	450 rads (Si), (1 Mev effective) in 10^{-8} sec, Source Temp <5 Kev; or 50 rads (Si), (1 Mev effective) in 10^{-8} sec, Source Temp ≥5 Kev.
Fast Neutrons	5.2	10^{12} neutrons/cm^2 at 1 Mev effective damage equivalent.
X-Rays	5.3	1 cal/cm^2, in 10^{-8} seconds from Sources at 1 to 15 Kev and Special Spectrum to 115 Kev.
Electromagnetic Pulse (Gamma-EMP)	5.4.1	30,000 volt/meter peak electric field; 80. ampere turns/meter peak magnetic field; 1 gauss peak magnetic flux density.
Electromagnetic Pulse	5.4.2	8,000 volt/meter peak electric field; no associated magnetic field.
Prompt Gamma, X-Rays and Neutron Multiple Pulses	6.1	One exposure to the maximum environments specified above plus nine exposures reduced by a factor of 25.
EMP Multiple Pulses	6.2	One exposure to the maximem environments specified above plus nine exposures reduced by a factor of 10.

vulnerable part of the system. Table B-2 summarizes the weapon effects by component. The effects are discussed in somewhat more detail below.

B.2.1 Prompt Ionizing Radiation

Because their influence and impact are essentially the same, gamma radiation and the higher energy components of the x-radiation will be discussed together. There are two aspects of the environment--the total dose and the dose rate--but for the quantities involved here, the total dose absorbed is far below the threshold of permanent damage and, therefore, need not be considered further. On the other hand, prompt ionizing radiation from a nuclear burst is delivered at a high rate. The major effect of this high dose rate is to produce ionization in various materials, which causes current and voltage changes in electronics. The threshold for such effects is generally considered to be about 10^7 rads/sec. Effects are observed in discrete components such as resistors and capacitors, but the most sensitive components are semiconductor devices. The principle effects are due to excess charge carriers generated throughout the materials by the ionization processes. The charge carriers are separated according to existing fields and result in transient currents that may cause secondary current surges.

There are three potential deleterious effects of the increase in current resulting from the prompt ionizing radiation--(1) generation of erroneous information; (2) burned-out or over-heated components; (3) latch-up (a change of state which can occur in integrated circuits where reverse bias is used for isolation at junctions; latch-up can cause additional current surges and destruction of the integrated circuit).

Shielding against gamma and high energy x-radiation is impractical because of the excessive weight penalties involved. Therefore, hardening against these effects requires use of radiation resistant components (e.g., dielectric isolation in integrated circuits) and, where possible, circumvention.

With respect to the computer, circumvention means to prevent the computer from acting on erroneous data resulting from the prompt radiation by turning the computer off during the critical period then correcting for the down period when the threat is past. This technique, unfortunately, results in a degradation of the CEP as information missed during the quiescent period must be extrapolated from data obtained in succeeding equivalent intervals. This technique is currently employed on Minuteman II and Minuteman III.

With respect to the electronics, in general, circumvention can be employed to momentarily remove all power from the vulnerable circuit

Table B-2

WEAPON EFFECTS ON MINUTEMAN G&C BY COMPONENT (U)

Lethal Mechanism	Component			
	Electronics Including Computer	Inertial Measuring Unit	Structure	Missile Cables and Wiring
Prompt ionizing, radiation	Current and voltage surges due to ionization which can cause burnout, erroneous information, latch-up			
Neutrons	Loss of gain in semi-conductors. Increased forward voltage drop in diodes			
X-radiation	Same as gamma radiation except dose is attenuated by shielding	Possible thermal-mechanical effects at bonds; not as critical as impact on electronics	Melting, spallation and blow-off effects but at much higher levels than electronics damage (see Appendix A)	
Electro-magnetic Pulse	Spurious charges in high gain currents, induced charges on insulator surfaces			Current and voltage surges induced in loops

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elements while the nuclear environment is threatening. Circumvention in this application is not as satisfactory as use of intrinsically hardened circuit components because it introduces a rather significant reliability problem. Also, not all circuits can tolerate removal of power and return to their proper function.

B.2.2 Neutrons

The vulnerability of the system to neutron effects is determined by the response of semiconductors, because the damage threshold of other electronic components and materials is several orders of magnitude higher. The important neutron damage mechanism is the production of crystal lattice defects by collision between fast neutrons and atoms of the lattice. Such defects are permanent and depend primarily on the time integrated (total) neutron flux. Certain transient operational effects are also present but these are small compared to the associated gamma ray pulse effects, primarily because of the time dispersion of the neutron pulse.

The crystal lattice defects created by the neutron damage result principally in a decrease in gain for bipolar transistors and an increase forward voltage drop across diodes. Secondary effects are changes in conductivity, carrier mobility, and doping concentration.

Shielding against neutrons is not feasible because of both space and weight limitations (low-density shielding is effective but large quantities are required). Therefore, hardening must be done on a component basis and, in addition, circuits must be overdesigned to provide adequate gain even after considerable attenuation. New semiconductor materials are expected to increase hardness significantly.

B.2.3 X-Radiation

A major portion of the nuclear energy from a nuclear burst is in the form of thermal radiation at such high temperatures that most of the radiation is in the x-ray spectrum. This radiation appears essentially instantaneously (10^{-8} to 10^{-7} seconds); consequently, the energy is delivered at an extremely high rate. Because x-rays are strongly absorbed in materials any object exposed to the x-ray environment accumulates a great deal of energy in its outer layers in minute fractions of a second. This, in turn, results in a rapid increase in heat content and temperature which, in turn, can lead to serious damage through melting, vaporization, structural deformation, spallation, and internal shock loading. Bonds between dissimilar materials are particularly vulnerable to x-ray damage because different absorption rates and coefficients of expansion can lead to debonding.

That portion of x-radiation which does penetrate to the electronics devices acts in the same manner as the harder x-rays and gamma rays and this radiation must be added to the prompt ionizing radiation in assessing effects on electronics.

There are two aspects to the problem of hardening to x-radiation--optimization of shielding and hardening of internal electronics. The purpose of the shield is to reduce the incident x-ray flux to such a level that the total ionizing radiation internal dose rate will not be detrimental. Hardening the electronics against x-rays uses the same techniques as hardening against gamma-rays, because the effect on system electronics is the same.

It is extremely important to minimize the weight of the shield so that missile payload, range, or both may be maximized. There are several considerations that must be made in optimizing an x-ray shield. One is the importance of the spectrum of the incident radiation. In the low-energy region of the electromagnetic spectrum, where the primary interaction with matter is by photoelectric absorption, high atomic number materials are most efficient. At high energies, where the primary interaction is via Compton effect, which is dependent on electronic density or mass of material, the shielding weight is less dependent on material. Therefore, the optimum shield for one incident spectrum will not necessarily be optimum for another. Within the photoelectric region, the existence of photoelectric absorption edges that occur at different energy levels for different materials complicate the selection of a minimum weight shield.

Because of the greater attenuation of lower energy photons, a beam of x-radiation tends to become harder (greater percentage of more penetrating radiations, i.e., higher energy) as it passes through material. In addition, a consequence of a photoelectric absorption is the almost immediate emission of characteristic x-rays (fluorescence radiation) of somewhat lower energy than the incident photons. Characteristic radiation is emitted at lower energy than the absorbed radiation in a region where the absorption coefficient is lower. Thus, it is more efficient to use shields made of a combination of two or more materials because of beam hardening and fluorescence effects.

B. 2. 4 Electromagnetic Pulse

Although the mechanisms are not fully understood, electromagnetic pulses are produced by nuclear weapons regardless of whether the event takes place inside or outside the atmosphere. In air, the principal source of electromagnetic fields is the gamma radiation, which initiates a current of electrons with primarily outward-directed velocities. This phenomenon appears as a rapidly expanding shell of negative charge. When asymmetry is introduced, by the ground, for example, in a near

surface burst, an electromagnetic pulse is propagated outside the immediate burst volume. The magnitudes of the electric and magnetic fields can be significantly greater than those encountered in electrical storms.

Areas of vulnerability include system cabling and interconnections, computer memory, high-impedance, high-gain circuits, components employing high-permeability materials, and large surface insulators where an electric charge may be stored. Interconnecting cables pose potential vulnerability due to the possibility of the creation of relatively large area loops. Magnetic field loop coupling will induce voltages proportional to the area enclosed by the loops. Such voltages may appear as spurious signals or even cause breakdown of cabling insulation. In addition, if ground loops of significant area occur, large currents may be induced in the circuit that could cause system failure, interruption, or excessive noise.

Common electromagnetic interference (EMI) shielding procedures provide adequate protection from the effects of the electric field of the electromagnetic pulse. In the absence of large holes, the missile skin provides essentially all the electric field protection needed. However, all openings in the outer skin must be covered with shielding material equivalent to the missile body section.

In contrast, low-frequency magnetic fields are not well shielded by materials and thicknesses quite adequate for the electric field protection. Therefore, some of the more sensitive components and systems may require additional magnetic shielding. In addition to shielding, large area circuit or ground loops must be eliminated or the area minimized, because the magnetic coupling is proportional to the area of the loop.

B.3 BOOST-PHASE SURVIVABILITY

The survivability of the Minuteman during boost phase is, of course, determined by its weakest component. For both Minuteman II and Minuteman III the electronics in the guidance and control subsystem are clearly the most vulnerable parts of the system. Table B-3 summarizes the results of Appendixes A and B, showing the vulnerability of the major subsystems to x-radiation.

Reasonable modifications to the Minuteman III post-boost propulsion system (discussed in Appendix A) could result in a 5-cal/cm^2 sure-safe level for that subsystem. Maximum sure-safe levels for the guidance and control subsystems utilizing only modifications are probably not large. On the other hand, replacement of these elements with intrinsically harder elements could ultimately raise the G&C subsystem to a level compatible with the other subsystems.

Table B-3

MINUTEMAN SUBSYSTEM VULNERABILITY (U)

System	Subsystem	Current Sure-Safe Level (cal/cm^2)	Potential Sure-Safe Level* (cal/cm^2)
Minuteman II	Propulsion System	5	5
	Guidance and Control	.75**	--
Minuteman III	Propulsion System	6 - 7	6 - 7
	PBPS	1	5
	Guidance and Control	1***	--

*Feasible modifications.

**1 to 5 Kev blackbody.

***1 to 15 Kev blackbody and special spectrum to 116 Kev.

B.4 GLOSSARY

Bar	A unit of pressure equal to 10^6 dynes/cm^2 or 0.9869 atmosphere.
Blackbody	An idealized body that absorbs all energy falling upon it. It reflects no energy and, if at a uniform temperature, emits electromagnetic radiation with a distribution characteristic of its temperature.
Blackbody Spectrum	The distribution of radiation intensity versus photon energy or wave length that is emitted from a blackbody; also known as a Planckian distribution.
Blowoff Impulse	Impulse applied to the material surface from vaporization caused by x-ray deposition in the material.
Compton Effect	The scattering of photons (of gamma or x-rays) by the orbital electrons of atoms. In a collision between a photon and an electron, some of the energy of the photon is transferred to the electron. Another photon, with less energy, then moves in a new direction at an angle to the direction of motion of the primary photon.
Dose	A total or accumulated quantity of ionizing radiation, or time-integrated dose rate.
Dose Rate	The quantity of radiation received per unit time.
Electron Volt	The kinetic energy of an electron based on its mass and the velocity attained through an acceleration produced by a potential difference of one volt (abbreviated ev). 0.1 ev = 1.6×10^{-12} ergs of energy.
Fast Neutron	A neutron with an energy level of 10 deV or more.
Fluence	The energy or number of particles transferred across a given area perpendicular to the direction of flow; also called time-integrated flux. Typical units are cal/cm^2 for x-rays, n/cm^2 or nvt for neutrons, rads (c) for gamma radiation.

Flux	The energy of number of particles transferred across a given area perpendicular to the direction of flow in unit time.
Photoelectric Effect	The process whereby a gamma or x-ray photon, with energy greater than the binding energy of an electron in an atom, transfers all its energy to the electron, which is consequently removed from the atom. The photon is totally absorbed in the process.
Prompt Gamma	The portion of the gamma environment that arises from fission and fusion in a nuclear anti-missile warhead, and from neutron absorption and inelastic scattering reactions with the missile materials. The prompt gamma radiation is emitted during the first few micro-seconds after detonation.
Rad	A unit of absorbed dose. One rad is equal to 100 ergs of absorbed energy per gram of absorbing material. This unit cannot be used to describe a radiation field.
Roentgen	A unit of exposure dose of gamma radiation or x-rays. It is defined precisely as the quantity of gamma radiation or x-rays such that the associated corpuscular emission per 0.001293 gram of air produces, in air, ions carrying one electrostatic unit quantity of charge of either sign. One roentgen of gamma radiation of x-rays results in the absorption of roughly 87 ergs per gram of air.
Source Temperature	Temperature refers to the kinetic energy of the particles composing a body in thermal equilibrium; source temperature is the temperature of a blackbody whose emitted radiation most nearly matches an observed spectrum.
Spallation	Material fracture caused by shock-induced tensile stresses.
Taps	Unit of impulse or momentum equal to 1 bar-μsec.

X-Rays — Electromagnetic radiation produced outside the atomic nucleus. X-rays have zero rest mass and zero charge. Hot and cold x-rays are terms describing a portion of the spectrum of electromagnetic energy. Cold, soft, low-energy, and low-temperature x-rays indicate blackbody source temperatures up to about 2 kev. Hot, hard, high-energy, and high-temperature x-rays indicate blackbody source temperatures above 2 kev.

B.5 REFERENCES

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